Environment and Ecology 40 (2C) : 899—912, April—June 2022
ISSN 0970-0420

Evaporation Reduction from on Farm Reservoir using Biological Shading

Ashish V. Sonawane, Sudhindra N. Panda

Received 30 November 2021, Accepted 20 January 2021, Published on 8 June 2022

ABSTRACT

Study was conducted to model evaporative water loss from the on-farm reservoir (OFR) with biological shading. Bottle gourd (*Lagenaria siceraria*) creeper was grown on inverted 'V' shape bamboo platform over the OFR as biological shading to suppress the evaporation from the OFR. Canopy growth model which is used to predict ground cover of the creeper (G_i) with respect to time using Normalized ET_o was applied to simulate growth of canopy cover on OFR embankment and bamboo frame over the OFR. Simulated values were compared with observed values which showed that there was a very close agreement between observed and predicted values. The R^2 values between observed and predicted canopy cover over the embankment for test years 2013-14 and 2014-15 were 0.96 and 0.97 respectively. Whereas the RMSE values for both the test years were 0.8% and 0.76% respectively. Similar results were obtained for observed and predicted canopy cover over bamboo frame during both the test years with R^2 values of 0.95 and 0.93. RMSE values were 7.86% and 8.34% respectively, for both the years under consideration. The radiation interception model developed by Hernandez-Suarez was modified and used to simulate the percentage of radiation interception (R_i) with respect to the water surface of the OFR under the biological shading. To estimate the water loss from covered OFR due to evaporation, evaporative water loss model (E_{loss}) was developed by accounting the fraction of radiation and heat energy not intercepted and the evaporation equation of the open OFR. The R^2 values between observed and predicted values were found to be very high (0.95 and 0.94) whereas RMSE values for both the years were found to be 0.050 m^3 day^{-1} and 0.056 m^3 day^{-1} respectively. It was also revealed that there was around 38.50% reduction in evaporation loss in shaded OFR in comparison with open OFR.

Keywords Biological shading, Canopy growth model, Evaporative water loss, Normalized ET_o, On-farm reservoir.

Ashish V. Sonawane*
Assistant Professor and Head, College of Agricultural Engineering and Technology, Dediapada, Navsari Agricultural University, Gujarat (India) 393030

Sudhindra N. Panda
Professor, Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, West Bengal (India) 721302
Email :
*Corresponding author

INTRODUCTION

Water is the most precious natural resource in the world, especially in the country like India which is going to be the most populous country in coming future. In addition, around 70% of the net sown area of the country is rain-fed and contribute only 40% of country's food grain production (Panigrahi 2011).

In eastern India, around 70% of cultivated area is rainfed. In the rainfed farming system, the crop production is entirely depends upon the south-west monsoon. Though the region receives wide range of mean annual rainfall, about 1200 -2000 mm, the rainfed crops suffer from the situation of drought or flood every alternate year. Studies revealed that nearly 80% of mean annual rainfall is concentrated in few storms of monsoon season. At least two long dry spells, each more than 10 days duration, during the crop growth stages are also likely to occur (Panigrahi and Panda 2003). High degree of temporal and spatial variation in the rainfall, unpredictable onset and withdrawal of monsoon accompanied by in-season long dry spells are some of the reasons attributed to poor productivity of the rainfed ecosystem of eastern India (Agarwal *et al*. 2004). Though the long term effects of changing climate are yet to be known precisely, it has been widely accepted that there will be alteration in the pattern of rainfall. The changing climate may affect the rainfed farming of the region adversely and would cause serious threat to food security.

To overcome this critical situation, there is increasing trend amongst the farmers of the region towards constructing an on farm reservoirs (OFRs). Water harvested in the OFR can be used for supplemental irrigation to satisfy the demand of two or more crops in critical dry spells with success and high pay off (Panigrahi and Panda 2003).

However, valuable water harvested in OFR gradually evaporates and percolates, which are two major outflow components of hydrologic system of OFR. Seepage loss from unlined OFR ranges from 45–67% whereas evaporation loss (E_{loss}) accounts to be around 30% (Guerra *et al.* 1990, Pal *et al.* 1994). It was also seen that, in some cases, water loss by evaporation and seepage accounts to be around 70% of the total water stored in OFR (Syamsiah *et al.* 1994). Seepage loss, however, can be controlled to a large extent by using polythene sheets or similar lining material (Verma 1981, Sharada and Shrimati 1994, Srivastava 2001).

The amount of stored water lost to evaporation depends on various factors like atmospheric evaporative demand, size of reservoir and storage method. There have been numerous attempts made to reduce the evaporation losses by altering storage design from increasing reservoir depth, by installing windbreaks or by covering reservoir surface (Brown 1988, Craig 2005). Different types of covers like chemical monolayers, floating covers and shade structures are differ by their relative effectiveness and economic viability (Cooley and Myers 1973, Cooley 1983, Craig 2005). Some other popular techniques are, mixing systems to reduce the thermal stratification of the water (Koberg and Ford 1965), reduction in mass and energy exchanges at the inter-phase water to atmosphere by using floating bodies (Daigo and Phaovattana 1999), modifying the water albedo by application of different colors (Cooley 1983) and the use of trees as wind breaks (Hipsey and Sivapalan, 2003, Hipsey *et al.* 2004). Use of shade also reduces evaporation significantly (Crow and Manges 1967, Cluff 1975).

Most of the methods available to suppress evaporation provide partial cover to the water surface. As evaporation from free water surface occurs at its potential rate, to a first approximation, it can be understood that evaporation losses are proportional to the evaporating area, and therefore water saving would be proportional to percentage of covered area (Cooley 1970).

However, most of these methods are not efficient in the long term and also are not technologically or economically viable particularly for the farmers of developing country like India. Secondly complete covering the OFR hinders the entry of rainwater inside the reservoir. Monolayers get punctured or dissolve during the events of rainfall and its effectiveness in the monsoon season reduced drastically (Barnes 2008). Cooley and Idso (1980) experimented with cover of lily pads as biological cover to intercept radiation. They observed only 2.9% reduction in E_{loss} as compared to that of in an open body of water. As aquatic plant themselves consume water from the OFR to meet their transpiration requirements, this measure could not be effective. By shading the water surface by cover crops (squash) with combination of tree crops such as banana (*Musa acuminate*) as wind break could reduce evaporation rate around 50% (Wardana *et al.* 1996). Condie and Webster (1997) used wind brakes around the large water body and developed an evaporation loss model. They have reported around 20% reduction in E_{loss}. Linacre *et al.* (1970) showed that the E_{loss}, from the swamp which is reed infested, is one-third of that from an open lake.

It is now well understood by various studies that any kind of shade, mechanical, chemical or biological, over the water surface helps in suppressing the evaporation loss. Biological measures seem to be more realistic and cost effective which can be employed even by a poor farmer. It would be more acceptable if a farmer could get extra income or benefit along with water saving by using creeper as a biological cover. Shading effect on the OFR by covering the water surface by canopy cover of creepers can be the feasible solution. The creeper canopy grown on the certain kind of wooden frame over the surface of OFR would intercept the incoming radiation and also minimize the effect of wind which may also reduce the evaporation rate. Creeper canopy would cause minimum hindrance to the rainfall falling over the OFR. Unlike chemical layers, which may give rise to water quality issues, creeper canopy cover does not deteriorate water quality so that other use of harvested water can also be possible.

Very few studies have been undertaken to evaluate the effect of biological shading with respect to reduction in E_{loss} from various sizes of the OFRs. The present study was undertaken to develop an E_{loss} model for various sizes of the OFRs with biological shading. The E_{loss} model consists of canopy growth and Radiation Interception (RI) (What is this ?) models. To simulate the growth rate of canopy cover on the bamboo frame installed over various sizes of OFR, the canopy growth model will be used. Whereas, RI model will be used to separate the fraction of radiation energy intercepted by the canopy cover from the net solar radiation. To develop the E_{loss} model, rest of the radiation energy which is not intercepted and coming on to the water surface will be used.

The present study aimed to evaluate the effectiveness of bottle gourd creeper cover for reducing evaporation loss from the OFR.

Theoretical background

Evaporation from a free water surface consists of heat and mass transfer to and from the air above the water surface. Therefore, the rate of evaporation depends on (i) the rate at which water molecules diffuse or are moved away from the water surface and (ii) the rate at which energy supplied to the region of interface.

The available energy in a given system can be defined in two parts, by the mass flux due to evaporation and associated heat flux.

Let us consider the evaporation taking place from the free water surface of area S [L^2] which is open to atmosphere. Whenever air temperature T_a [θ], surface water temperature T_w [θ] and mass flow rate of evaporating water, m [MT^{-1}] becomes constant, steady state condition develop rapidly.

For a control volume of unit area considering a vapor layer between the water surface at T_w and the ambient air at T_a, the energy balance at steady state can be given by

$$\epsilon = q + \frac{m}{S} (h_i - h_e) = 0 \qquad (1)$$

Where, ϵis the rate of change of the energy of the control volume with respect to time [MT^{-3}], q is the rate of heat (energy) transfer from the surroundings [MT^{-3}], and h_i and h_e [L^2T^{-2}] are the specific enthalpy at the inlet and the exit of the control volume. Also we can define the evaporation rate, E [LT^{-1}], as

$$E= \frac{m}{\rho S} \qquad (2)$$

By applying the definition of enthalpy for ideal gases (Moran and Shapiro 1988), the energy balance in equation (1) can be written as :

$$q + E \rho c_p (T_w - T_a) = 0 \qquad (3)$$

Where, ρ[ML^{-3}] and c_p are the density and specific heat capacity of water vapour [$L^2T^{-2}\theta^{-1}$], respectively.

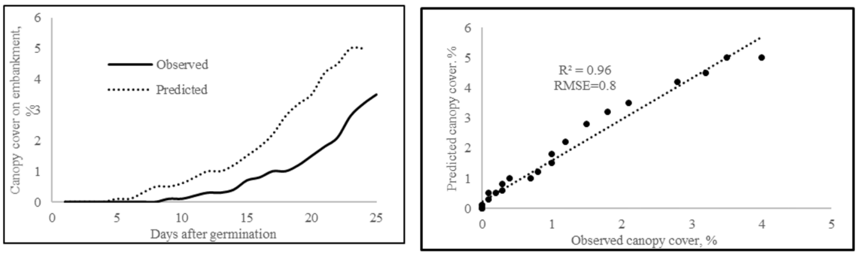

Fig. 1. Observed and predicted canopy cover on embankment in 2013-14.

Penman's equation explains evaporation from water bodies as the combination of water loss due to radiation and heat energy andthe aerodynamic removal of water vapour from a saturated surface. The general form for the combination equation is expressed as

$$E = \frac{\Delta}{(\Delta+\gamma)} R_n + \frac{\gamma}{(\gamma+\Delta)} E_\alpha \qquad (4)$$

Where, E=evaporation rate, Δ = slope of the saturation vapour pressure curve; γ=psychometric constant; Rn=net radiation and Eα =aerodynamic functions

$$E_\alpha = f(u)\ (e_s — e_d) \qquad (5)$$

Where, $f(u)$ = wind function and $(e_s – e_d)$=vapor pressure deficit

It implies that the evaporative water loss from water body is a function of radiation and heat energy and aerodynamic functions. Interception of radiation energy, the vital energy source for causing evaporation (Watts 2005), can cause reduction in evaporative water loss (E_{loss}) and further reduction can be achieved by lowering either the vapour pressure deficit or the wind function or both above the water surface. Unlike other field crops, the creepers have the ability to creep on the ground, as well as on some support and cover up the underlying surfaces with their emerging canopies. The idea of developing a creeper cover over the water surface of the OFR for interception of solar radiation and therebyreducing E_{loss} arises from this concept. Variety of creepers, namely, bottle gourd (*Lagenaria siceraria*), fieldpumpkin (*Cucurbita pepo*), bitter gourd (*Momordica Charantia*) and cucumber (*Cucumis sativus*) are widely grown in the region to support household vegetable requirements.

Model formulation

Canopy growth model

It is important to predict crop canopy development for the estimation of crop evapotranspiration. It is well known fact that transpiration from the plant body is very closely related with the crop canopy size whereas the evaporation from soil is affected by the shading over the soil surface. As reported by Gallardo *et al.* (1996) and Ventura (2001), after the germination, percentage canopy cover (G_i) on any day is a function of normalized reference crop evapotranspiration (ET_o).

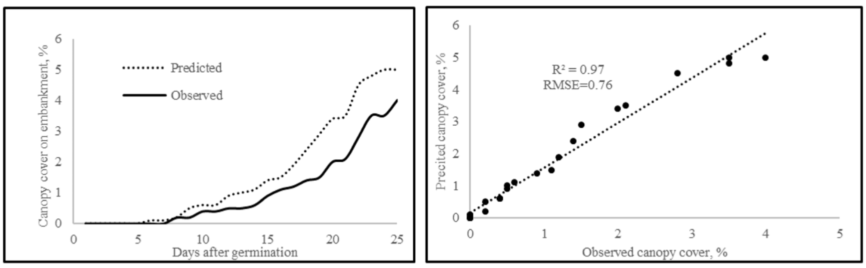

Fig. 2. Observed and predicted canopy cover on embankment in 2014-15.

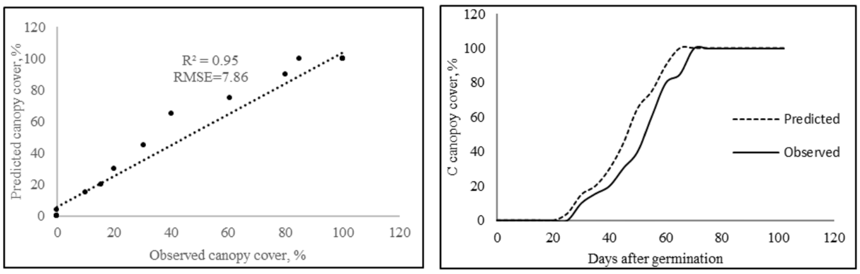

Fig. 3. Observed and predicted canopy cover on bamboo frame in 2013-14.

Canopy growth models which are generally employed are function of accumulated diurnal average temperature above the lower development threshold (degree days) and predict the leaf area index (LAI) only. However it is more appropriate to use percentage canopy cover (G_i) than LAI as the layering of leaves are closer to ground surface. Similarly is advantageous to use normalized reference crop evapotranspiration (ET_o) instead of degree days as there is only one input parameter is needed to determine canopy cover and crop evapotranspiration. This is not very clear.

In the present study the duration of crop was around 100 days and the sowing date was decided by taking into consideration the cessation of monsoon in such way that, when there is high evaporative period, the OFR should be optimally covered.

Cumulative reference crop evapotranspiration at the end of the crop season (Cn) is expressed as

$$C_n = \sum_{i=1}^{n} (ET_0)\ i \qquad (6)$$

Where,
i =time index taken as 1 day in the study.

Penman-Monteith equation (Allen *et al.* 1994) was used to determine daily ET_o values of the crop season using local climatic data.

The normalized cumulative reference crop evapotranspiration (N_i) on i^{th} day of the season can bedetermined as

$$N_i = \frac{\sum_{i}^{j} C_i}{Cn} \qquad (7)$$

Where,

C_i=cumulative ET_o on i_{th} day and j=day on which the creeper attains maximum ground canopy cover after germination.

The *Ci* is computed by summing up the daily values of ET_o from i=1 to the required day. (The *Ci* is cumulative ET_o of the day. How is this calculated by summing up ET_o ?)

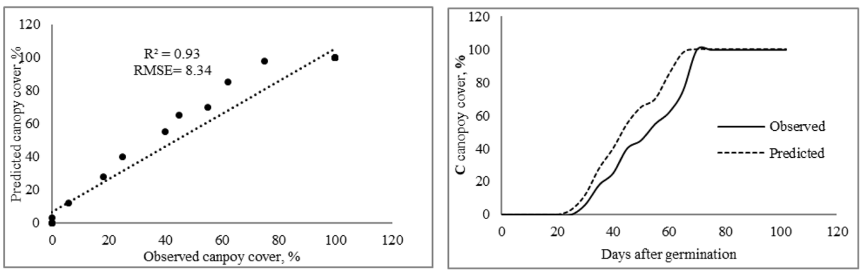

Fig. 4. Observed and predicted canopy cover on bamboo frame in 2014-15.

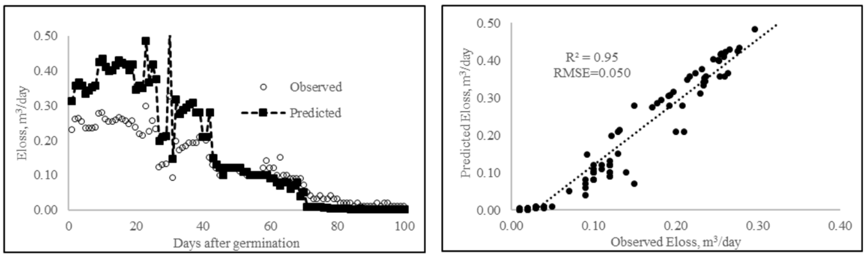

Fig. 5. Observed and predicted E_{loss} from creeper covered OFR 2013-14.

Depending upon the length and width of creeper cover Gi value can be estimated. At particular day in the life cycle of creeper, it attains maximum ground cover (*Gn*) this implies that on that day the length and width of canopy is maximum and it is assumed that this condition remain until the last stage of the crop cycle. (Maximum ground cover is attained during max vegetative stage, which does not continue up to maturity). As reported by Sahoo *et al.* (2010) the relation between N_i and G_i was established by curve fitting using Curve Expert v. 1.3 software which shows that the values of computed N_i was ranged from 0.03 to 0.91 whereas observed value of G_i ranged from 0.09 to 100% from the germination to the day of attaining maximum canopy cover. To estimate the canopy cover on any day, the following formula, which is the canopy growth model, was used.

$$Gi \, \frac{G_n}{\left\{ 1+ae^{-bN_i} \right\}} \qquad (8)$$

Where, a and b are the growth coefficients, values of which was obtained by Curve Expert v. 1.3 software and this model was used to simulate the canopy growth dynamics over the time.

3.2 Radiation interception model

Sunlight when incident on cropped area gets intercepted by the crop canopy and partly by bare soil surface (What do you mean for covered soil and open soil surface ?). At any day (i_{th} day for instance) of the crop season, percentage intercepted solar radiation by crop canopy is $R_i = 100R/R_s$ (where, R= amount of radiation intercepted by canopy and R_s= fraction of total global radiation), which is used in evapotranspiration model to differentiate transpiration (T_i) from soil evaporation (E_i). The fraction of solar radiation intercepted on i[th] day by crop canopy is given by Ri/100 and that of intercepted by bare soil is 1– R_i/100. Hernandez-Suarez (1988) developed RI model for various field crops which determine percentage RI with respect to net radiation falling of ground using percentage canopy cover on the ground.

This model is represented as :

$$R_i = 0.63 + 1.373\, G_i - 0.0039 G_i^2 \quad (9)$$

Where, R_i=percentage radiation intercepted by canopy cover on i[th] day.

It is assumed that the ratio of crop transpiration to crop evapotranspiration is same as the fraction of solar radiation intercepted by the crop canopy (Sahoo *et al.* 2010). (Reference). This means that there is a direct proportion between RI of a crop and transpiration rate. It is also well known that as the canopy area increases the interception of solar radiation also increase and proportion of solar radiation not intercepted decreases. As the interception of radiation increases, the evaporation from the soil surface under the crop canopy also decreases. So the fact is established that the canopy area of the crop increases, the transpiration rate of the crop increases and at the same time the evaporation rate from the soil surface under the canopy is decreased. This fact has been modelled in various studies by Gallardo *et al.* (1996), Ventura (2001) and Buyuktas and Wallender (2002) for determining the percentage of radiation energy intercepted by the canopy cover of field crops.

In the present study, this canopy growth model

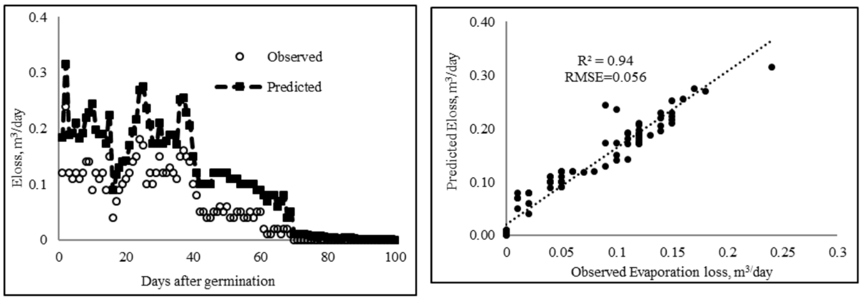

Fig. 6. Observed and predicted E_{loss} from creeper covered OFR 2014-15.

was used to estimate the G_i and RI model to determine intercepted radiation (R_i) for the bottle guard creeper canopy.

A growing creeper has the fixed values of maximum length and width. It is desirable that the entire OFR open space should be covered by the creeper canopy so that there is minimum evaporation loss of water. So it is important to determine percentage open space covered by the canopy with respect to total open space of OFR to estimate the RI which affects the open surface evaporation. However, the open space of OFR is function of OFR size. So to increase the applicability of model, it is important that the canopy growth model should take care of various sizes of OFRs. This problem can be addressed if G_i value of the creeper cover converted into percentage open space covered (O_i).

Conversion of percentage ground cover to open

Sahoo *et al.* (2010) conducted the field experiment to establish the relation for conversion of the canopy cover from G_i to O_i and the corresponding RI before and after entering the open space. It was assumed that growth dynamics of single creeper represented dynamics of all creepers planted around the OFR. In order to differentiate the covered area of open space from the total area of canopy cover, the embankment area under canopy cover should be eliminated. Sahoo *et al.* (2010) suggested the following expression for RI and same was used in the present study.

$$Ri = 1.373\ Oi - 0.0039(Oi)^2 \qquad (10)$$

Evaporation from the OFR covered with the canopy

Process of evaporative water loss from the creeper covered OFR occurred in the two stages. The first stage is when the open space of OFR is not covered by creepers. In this stage, the radiation falling directly over the water surface and vapor pressure deficit at water surface causes the evaporation. The second stage is when the open space is being covered by the creepers. At this stage, fraction of radiation is intercepted by the creeper cover and fraction which is not intercepted is responsible for the evaporative loss from the OFR. The fraction of radiation intercepted by creeper depends upon dynamics of creeper growth over OFR. As the open space decreases due increase in creeper cover over the OFR, the fraction of radiation intercepted by canopy increases and in turn reduces the evaporation loss. This second stage starts when creeper enters in the open space of OFR and lasts until the end of crop season. As reported by Doorenbos and Pruitt (1977), Class A pan evaporimeter data can be used to determine evaporation from open water body having depth upto 5 m. As the depth of OFR in the present study was around 2.4 m, pan evaporimeter data of experimental site was used to determine evaporative water loss.

Evaporative water loss in stage first (Open OFR)

In this stage the creepers are still not entered in the open space of OFR, when there is no interception of radiation and the evaporative water loss (m^3day^{-1}) can be given by the following expression.

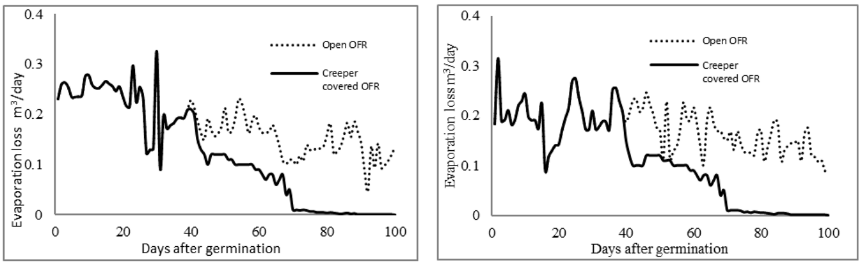

Fig. 7. Time series E_{loss} from creeper covered OFR and open OFR during 2013-14 and 2014-15.

$$E_{loss} = Kp\ (E_{pan})\ (WSA) \qquad (11)$$

Where, Kp=pan coefficient; Epan=pan evaporation (m day^{-1}) and WSA=water spread area (m^2).

As reported by Saxena and Tiwari (1988), pan coefficient for the experimental site is 0.74 and the same was used for the calculation purpose.

Evaporative water loss in stage second (creeper covered OFR)

The creeper canopy of bottle guard grows over the triangular bamboo frame, which is described in detail in subsequent sections, creates the open space between water surface and creeper cover, which allows the free movement of air over the water surface. Also there is no restriction on the water vapor movement over the water surface as there is no restriction on ventilation by creeper cover. Therefore it is assumed that there is no effect of creeper cover on movement of the wind and water vapor except the RI. So pan coefficient of the Class A pan evaporimeter is sufficient to take care of the effect of wind and water vapor deficit in case of the creeper covered OFR. This implies that the evaporative water loss in the case of covered is the function of solar radiation which is not intercepted by the canopy (i. e., 1−Ri /100). Therefore evaporation loss (m^3 day^{-1}) in case of shaded OFR can be expressed by following equation :

$$E_{loss} = Kp\ (E_{pan})\ (WSA)\ (1-Ri/100) \qquad (12)$$

MATERIALS AND METHODS

Study area

Field experiments were carried out in the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India during the *rabi* seasons of 2013-14 and 2014-15 to develop a canopy cover of bottle gourd on OFR using bamboo frame for reducing E_{loss} for the OFR with creeper cover followed by their evaluation study. The experimental site was situated at 22°19´ N latitude and 87°19´ E longitude at an altitude of 48 m above the mean sea level. The average annual rainfall of the region is around 1,500 mm and comes under typical humid subtropical region most of which (around 1200 mm) is concentrated in the monsoon season i.e., June to September. The spatial and temporal variation of the rainfall is very high in the region, which is the feature of the monsoon.

Various important climatic parameters collected from meteorological observatory of the department during the study period were mean maximum temperature 26.5°C, mean minimum temperature (16.8°C), mean maximum relative humidity (88%), mean minimum relative humidity (42%), average daily actual sunshine hour (6.8 h), average net radiation (14.5 MJ m^{-2} day^{-1}), and average wind velocity (2.1 m s).

Canopy development on bamboo frame

An experiment was conducted in the crop field to establish a relation between ET_o and area covered by the creeper (bottle gourd). The OFRs used in the study were square-shaped, pyramidal dugout type ponds, with the depth of 2.4 m from ground level. The side slope of the OFR was 1:1; the dimensions of each OFR were 9.8 × 9.8 m, the berm width at ground level was 30 cm and height, top width, bottom width and side slope of the embankment of the OFR were 30, 30, 90 cm and 1:1, respectively. Dimensions of the OFR at the ground level and bottom level were 7.4 × 7.4 m and 3.4 × 3.4 m. OFR was lined at bottom and sided by 600-gauge plastic film overlaid by a 30 cm soil layer, to prevent percolation loss. To collect the surface runoff from the field, inlet pipes were placed at the side of the OFRs. Two such OFRs were selected for the study. One being shaded with creeper canopy supported on bamboo frame and other one is open surface without any evaporation control measure. The evaporation dynamics of these two OFRs were compared with each other.

To estimate the coverage of open area of an OFR by creeper, inverted 'V' shape bamboo frame was made and was kept on the open surface of an OFR. The inverted 'V' shape not only provide canopy the larger area to spread but also facilitate easy harvesting of bottle guards using a simple bamboo having hook at one end, compared to flat frame. Using the flat frame by keeping poles directly on the embankment would lead to the bending of the poles at the center of the OFR due to the weight of the growing creeper canopy. This may cause the condition that the canopy cover will touch the water surface or get submerged in the OFR water during the events of heavy rainfall. This would damage the branches and leaves of the creeper in contact with water, which in turn not only reduces the effect of the canopy cover with respect to RI, but also may hamper the growth of creepers. Using inverted 'V' shape also facilitates good aeration at the surface of OFR which would help in maintaining water quality.

Rigid nylon wire was meshed to form grids of size 5 cm×5 cm across entire bamboo frame. The square grid of nylon wire so formed was used to measure the percentage of open space covered (O_i) by the creeper canopy. Photographs of canopy cover on mesh were taken regularly for analysing the area covered by canopy over the frame. Seeds of bottle guard were sown around the dyke of OFR, by maintaining distance of 0.3 m between the plants outside the embankment of OFR. Sowing of seeds too close to the embankment could puncture the lining material, so care was taken to sow the seeds far enough to safeguard the lining material of OFR. The dynamics of the canopy cover over the open space was measured based on the number of grids covered by creeper canopy.

As withdrawal of monsoon in the region is around last week of September, the seeds were sown in mid September (i.e., 15-16 Sept). This timing of sowing ensures well spread canopy over the frame during the days of mid October to early November, which characterized by high evaporative period. As during this high evaporation period, the OFR get covered by large extent, the E_{loss} reduces significantly. If there is early sowing of creepers, the coverage would hinder the rainfall over the OFR surface, which may reduce the water harvesting potential of OFR. So the ideal period for sowing of seeds was decided to be mid September. Length creepers were measured daily till the creepers reached to the frame. Meteorological data were collected from the department observatory to estimate evapotranspiration of plants. The day on which maximum surface was covered by canopy (G_n), the width and length were measured. The maximum open surface area of the OFR was around 96 m^2 which was totally covered by the creepers on the frame.

Evaporative water loss measurement

To estimate the depth of water inside the OFR, graduated staff was installed at the center of OFRs Depth of water inside the OFR was noted on daily basis. As the OFR was lined, from sides and bottom by lining material, the seepage loss was assumed to be negligible. The depletion of water level, at any day, accounts for the observed E_{loss} from OFR for the respective day. Similarly, the volume of water lost due to evaporation was estimated on daily basis using the depletion water level (i.e., difference in initial and final depth of water level during the time interval) and depth volume relationship curve of an OFR. The volume of irrigation water lifted for irrigation purpose was also estimated by water level depletion and corresponding depth volume relationship of an OFR, during the time of irrigation.

As the mustard crop was grown in the field of duration 90 days, the observation pertaining to E_{loss} was taken for around 100 days, i.e., end of first crop season to harvest of second crop. The E_{loss} model developed to compute evaporative water loss from the creeper covered OFR uses daily evaporation rate recorded by a Class A pan evaporimeter installed in the meteorological observatory of the department. Daily water spread area (WSA) (what is this ?) of the OFR was also monitored. The experimental site is located at a distance of 100 m from the observatory. The rate of evaporation was recorded on a daily basis using Class A pan evaporimeter. As reported by Saxena and Tiwari (1988) for the experimental site, the pan coefficient value of 0.74 was used for the calculation purpose in the model. Water balance of an OFR was carried out based on volume and converted again in terms of depth using depth volume relationship of OFR. The depth of OFR water was then used to compute the WSA using the model. To compute the evaporative water loss from the OFR which is shaded by creeper, the fraction of radiation energy not intercepted by the canopy cover ($1-R_i/100$) was used.

Sahoo *et al.* (2010) showed that, canopy growth model for estimating ground cover can be used efficiently for predicting coverage of canopy over the embankment and the open space of OFR and therefore this model was used in the study to study canopy growth dynamics.

Various experimental data regard to model parameters were collected during the experiment to evaluate the canopy growth model for bottle gourd and the E_{loss} model for the OFR with canopy shading. To evaluate the performance of models, the statistical analysis was carried out to estimate coefficient of determination (R^2) and RMSE.

RESULTS AND DISCUSSION

Canopy cover over the OFR

Growth of creeper canopy over the OFR from the sides of embankment to the open space over the OFR on the bamboo frame, consists of two phases. In first phase creepers grew towards the embankment and eventually covered the portion of the embankment. After covering the embankment, the creepers moved over the bamboo frame with the help of nylon net and covered the open space over the OFR subsequently. In both of these phases the same model was used to study the dynamics of creeper canopy growth. To validate the model performance, coefficient of determination (R^2) and RMSE for observed and predicted values were determined.

Canopy development on the embankment

Statistical analysis of the experimental revealed that there was very close agreement between observed and predicted values of canopy growth over the embankment. High R^2 and low RMSE values were obtained in both the years under consideration. In 2013-14 the R^2 value between observed and predicted canopy cover was estimated to be very high (0.96) with low RMSE (0.8%) (Fig. 2). Similarly in the year 2014-15, the corresponding values of R^2 and RMSE were 0.97 and 0.76% respectively (Fig. 3). Dynamics of creeper cover with respect to time over the embankment is shown in Figs. 2–3. This was clearly understood that, there was no significant difference between observed and calculated canopy growth rate. In the similar study, reported by Sahoo *et al.* (2009), there was a large lag between the observed and predicted growth rate. It was due to nutrient deficiency in the soil near the OFR embankment. To overcome this problem, doses of recommended fertilizers were applied during the sowing of the bottle guard seeds. It can be also seen that, creeper canopy took around 3-4 weeks to cover the embankment completely before it reaches to open space of OFR. This finding would help in decision making of the suitable sowing time of the bottle guard seeds. Keeping this in mind, around 3-4 weeks are required for a healthy creeper to cover the embankment part of the OFR after germination, which suggests the accurate sowing time.

Canopy development on the bamboo frame

The canopy growth model was found to perform efficiently in estimating creeper cover dynamics on bamboo platform also. The high values of R^2 and lower RMSE values between observed and predicted values in both the years of assessment revealed the same. In 2013-14 and 2014-15, the R^2 value between observed and predicted canopy cover was found to be 0.95 and 0.93 and the RMSE values were around 7.86 and 8.34%, respectively (Figs. 4–5). It can be also seen from the graph of growth rate with respect

Table 1. Sample calculation of E_{loss} from covered and open OFR.

Sl. No.	Days after germi-nation	Canopy cover (%)	Ri (%)	(1-Ri)/ 100 (Frac-tion)	E_{loss} from open OFR (m^3 day^{-1})	Predicted E_{loss} From creeper covered OFR (m^3 day^{-1})	Difference in E_{loss} (open OFR predic-ted) (m^3 day^{-1})	Obser-ved E_{loss} from creeper covered OFR (m^3 day^{-1})	Diffe-rence in E_{loss} (ob-served predic-ted) (m^3 day^{-1})
				From date of germination to 4th day					
1	1	0.000	0	1	0.31	0.31	0	0.23	-0.08
2	2	0.009	0	1	0.36	0.36	0	0.26	-0.1
3	3	0.014	0	1	0.37	0.37	0	0.26	-0.11
4	4	0.020	0	1	0.36	0.36	0	0.25	-0.11
				Days 12 to 18 after germination					
5	12	0.25	0	1	0.40	0.40	0	0.25	-0.15
6	13	0.29	0	1	0.40	0.40	0	0.25	-0.15
7	14	0.36	0	1	0.41	0.41	0	0.26	-0.15
8	15	0.40	0	1	0.43	0.43	0	0.27	-0.16
9	16	0.48	0	1	0.42	0.42	0	0.26	-0.16
10	17	0.55	0	1	0.42	0.42	0	0.26	-0.16
11	18	0.58	0	1	0.40	0.40	0	0.25	-0.15
				Days 30 to 38 after germination					
12	30	3.30	0	1	0.52	0.52	0	0.33	-0.19
13	31	3.80	0	1	0.15	0.15	0	0.09	-0.06
14	32	4.25	0	1	0.32	0.32	0	0.20	-0.12
15	33	4.80	0	1	0.28	0.28	0	0.17	-0.11
16	34	5.25	0	1	0.29	0.29	0	0.18	-0.11
17	35	5.80	0	1	0.29	0.29	0	0.18	-0.11
18	36	6.50	0	1	0.30	0.30	0	0.19	-0.11
19	37	7.00	0	1	0.31	0.31	0	0.19	-0.12
20	38	7.50	0	1	0.30	0.30	0	0.19	-0.11
				Days 60 to 66 after germination					
21	60	84.30	86.25	0.14	0.15	0.09	0.06	0.12	0.03
22	61	89.50	90.30	0.10	0.15	0.09	0.06	0.12	0.03
23	62	93.50	92.70	0.07	0.13	0.08	0.05	0.10	0.02
24	63	98.25	94.40	0.06	0.14	0.07	0.07	0.09	0.02
25	64	100.00	97.80	0.02	0.14	0.08	0.06	0.10	0.02
26	65	100.00	98.50	0.02	0.12	0.08	0.04	0.10	0.02
27	66	100.00	98.50	0.02	0.13	0.06	0.07	0.09	0.03
				Days 93 to 100 after germination					
28	93	100.00	98.50	0.02	0.143	0.001	0.142	0.010	0.009
29	94	100.00	98.50	0.02	0.094	0.001	0.093	0.020	0.019
30	95	100.00	98.50	0.02	0.099	0.001	0.098	0.020	0.019
31	96	100.00	98.50	0.02	0.108	0.001	0.107	0.010	0.009
32	97	100.00	98.50	0.02	0.120	0.001	0.119	0.010	0.009
33	98	100.00	98.50	0.02	0.136	0.001	0.135	0.010	0.009
34	99	100.00	98.50	0.02	0.143	0.001	0.119	0.010	0.009
35	100	100.00	98.50	0.02	0.094	0.001	0.139	0.010	0.009
Total E_{loss} in season					**21.06**	**17.12**	**3.94**	**12.95**	
Percentage reduction in E_{loss}					=(21.06-12.95)/21.06 =38.50%				

to time that, during both the years, there was a little time difference (around a week) between observed and predicted canopy growth to cover the bamboo frame. The results revealed that the creeper canopy growth model is highly efficient and has high applicability. Thus is can by understood that, as concept of converting G_i to O_i for predicting R_i is affirmed , the model can be used to predict dynamics of canopy coverage of the embankment and bamboo frame and valid for different sizes of OFR (Sahoo *et al.* 2009).

5.1.3 Evaporative Water Loss from the OFR with Biological Shading

The experimental data of observed and predicted Eloss from canopy covered OFR was statistically analyses and it was found that, there was very close agreement between these observations for both the years under considerations. For the year 2013-14 and 2014-15, the value of R^2 were > 0.94 andRMSE values were found to be <0.056 m^3 day-1.These high values of R^2 and lower values of RMSE showed that the model has high applicability, repeatability and efficiency.

Graph of temporal variation of Eloss showed that, the Eloss remains high up to 40thday of germination in 2013-14 (Fig. 6) and up to the 45thday in 2014-15 (Fig. 7) and then dropped down significantly up the end of the observation period. This variation was attributed to the fact that, in the initial period of canopy growth after germination, there was absence of canopy cover over the open space of the OFR. It can be observed that, upto day 25^{th} in 2013-14 and day 35^{th} in 2014-15, there was absence of complete coverage of canopy. However during around 40^{th} day to 70^{th} day in 2013-14 and during45th day to 70^{th} day in 2014-15, there was maximum canopy coverage over the open space and thus minimum RI. As the percentage of open space covered increased, the RI found to have increased after the 40th and 45^{th} days in 2013-14 and 2014-15, respectively.

It is obvious that as there was increase in R_i, there has been decreased fraction of radiation energy not intercepted $(1-R_i/100)$ this was resulted in to proportionate reduction in E_{loss}.

It can be observed from the Figs. 6, 7 that, the effect of canopy cover on Eloss was almost negligible until the 20–25% of its maximum canopy cover was achieved. This observation is important from the view of timing of the sowing of creepers. It is also expected that, there should be complete coverage of canopy over the OFR during the high evaporative periods. So timing sowing of creepers should be based upon the meteorological data analysis and knowledge of dynamics of creeper growth, with due allowance to the initial period, during which the E_{loss} does not get affected by canopy coverage, so that maximum amount of water can be saved.

5.2 Assessment of Reduction in Evaporative Water Loss from the OFR

Observed evaporative water loss from creeper covered OFR was compared with predicted Eloss from the open OFR on temporal basis, where both OFR had equal dimensions.

To determine evaporation loss from open OFR on daily basis, Eq.12 was used and then it was compared with observed E_{loss} from the creeper covered OFR. By knowing the E_{loss} from both the cases, percent reduction in E_{loss} in covered OFR with respect to open OFR was also calculated. Table 1 shows the sample calculation of E_{loss} from open and creeper covered OFR in 2013-14 for selected duration.

Fig. 8 shows the E_{loss}, from both the OFRs during test years of 2013-14 and 2014-15. It was observed from the time series graphs that, until the effective cover of creeper canopy gets developed on the bamboo frame, the Eloss from both the OFRs remains equal. As the effective biological shading started to get established, gradual reduction in E_{loss} from shaded OFR was observed as compared to Eloss from open OFR. Cumulative E_{loss} from shaded OFR in the year 2013-14 and 2014-15 was found to be 12.95 and 11.90 m^3 respectively, whereas corresponding values for open OFR were 21.06 and 20.12 m^3 respectively. This implies that, the reduction in percentage Eloss from biologically shaded OFR compared to open OFR was around 38.5% and 40.8% in respective years. Similar kinds of results were reported by Sahoo *et al.* (2009) in which bottle guard was used as biological shading and Wardana *et al.* (1996) using a squash cover on the water surface and a wind break around the OFR.

It was also found that, there was no significant variation in observed and predicted E_{loss} values from the OFR, which revealed that the model used in the study is highly predictable and efficient.

CONCLUSIONS

Study was carried out to control the evaporation from OFR using biological cover of bottle guard creeper. Canopy growth model and E_{loss} model were developed and these models were simulated for percentage canopy cover and loss of water by evaporation from OFR which was shaded by creeper canopy. The results obtained by model simulation were compared with observed data. It was revealed from the experiment that the canopy growth model shows a high agreement with the estimated canopy cover on the inverted 'V' shape bamboo frame, just by using one input parameter i.e. ET_o. The E_{loss} was also found to be very highly predictable with high R^2 values between observed and predicted water loss in both the test years (2013-14 and 2014-15). Therefore it can be concluded that, the canopy growth model has the high applicability for OFRs having different dimensions in rainfed areas. It was also found that there was considerable reduction in evaporation from OFR which was shaded by creeper canopy as compared to the OFR which was open. The bottle guard creeper not only provides biological shading and reduce the evaporation with low initial investment, it also create an opportunity of extra income to farmers. Biological shading using creeper canopy can be an effective and cost efficient technique for reduction of evaporative water loss from OFR to the large extent.

REFERENCES

Agrawal MK, Panda SN, Panigrahi B (2004) Modeling water balance parameters for rainfed rice. *J Irri drainage Engg* 130 (2) : 129—139.

Allen RG, Smith M, Pereira LS, Perrier A (1994) An update for calculation of reference evapotranspiration. *ICID Bull* 43 : 35— 92.

Bainbridge DA (2001) Buried clay pot irrigation : A little known but very efficient traditional method of irrigation. *Agricult Water Manage* 48 (2) : 79-—88.

Barnes GT (2008) The potential monolayer to reduce evaporation poration of water from large storage structures. *Agricult-Water Manag* 95 : 339—353.

Batchelor C, Lovell C, Murata M (1996) Simple microirri gation techniques for improving irrigation efficiency on vegetable gardens. *Agricult Water Manage* 32 : 37—48.

Brown JAH (1988) The potential of reducing open water evaporation losses: A review, paper presented at hydrology and water resources symposium. *Aust Natl Univ Canberra* 1—3 Feb.

Buyuktas D, Wallender WW (2002) Enhanced subsurface irrigation hydrology model. *J Irrig Drain Engg* 128 (3) : 168—174.

Cluff CB (1975) Engineering aspects of water harvesting research at the University of Arizona. Proceedings Water Harvesting Symposium, Phoenix, Arizona, pp 27—39.

Condie SA, Webster IT (1997) The influence of windstress, temperature and humidity gradients on evaporation from reservoirs. *Water Resour Res* 33 : 2813—2822.

Cooley KR (1970) Energy relationships in the design of floating covers for evaporation reduction. *Water Resour Res* 6 : 717—727.

Cooley KR (1983) Evaporation reduction: Summary of long-term tank studies.*J Irrig Drainage Engg ASCE* 109: 89—98.

Cooley KR, Idso SB (1980) Effects of lily pads on evaporation. *Water Resour Res* 16 : 605—606.

Cooley KR, Myers LF (1973) Evaporation reduction with reflective covers, *J Irrig Drainage Engg ASCE* 99 : 353—363.

Craig IP (2005) Loss of storage water due to evaporation A literature review, Univ. Of South. Queensl Toowoomba, Australia.

Crow FR, Manges HL (1967) Comparison of chemical and non-chemical techniques for suppressing evaporation from small reservoirs. *T ASAE* 10 : 172—174.

Daigo K, Phaovattana V (1999) Evaporation and percolation control in small farm ponds in Thailand. *Japanese Agricult Res Quart* 33 : 47—56.

Doorenbos J, Pruitt WO (1977) Guidelines for predicting crop water requirements. FAO irrigation and drainage paper 24 FAO Rome.

Gallardo M, Snyder RL, Schulbach K, Jackson LE (1996) Crop growth and water use model for lettuce. *J Irri Drainage Engg* 122 (6) : 354—359.

Guerra LC, Watson PG, Bhuiyan SI (1990) Hydrological analysis of farm reservoirs in rainfed areas. *Agricult Water Manage* 17 (4) : 351—366.

Hernandez-Suarez M (1988) Modeling irrigation scheduling and its component and optimization of water delivery scheduling with dynamic programming and stochastic ET_o data. PhD thesis. Univ of California Davis Calif.

Hipsey MR, Sivapalan M (2003) Parameterizing the effects of a wind shelter on evaporation from small water bodies. *Water Resour Res* 39 (12) : 1339—1345.

Hipsey MR, Sivapalan M, Clement TP (2004) A numerical and field investigation of surface heat fluxes from small wind-sheltered waterbodies in semiarid Western Australia. *Environ Fluid Mechanics* 4 : 79—106.

Koberg GE, Ford ME (1965) Elimination of thermal stratification in reservoirs and resulting benefits. United States Geological Survey, paper 1809-M.

Linacre ET, Hicks BB, Sainty GR, Grauze G (1970) The evaporation of a swamp. *Agricult Meteorol* 7 : 375—386.

Mondal RC (1974) Pitcher farming: A simple low-cost method of irrigation. *Appropriate Technol* 13 : 7—8.

Moran MJ, Sahpiro HN (1988) Fundamentals of Engineering Thermodynamics. John Wiley, New York.

Pal AR, Rathore AL, Pandey VK (1994) On-farm rainwater storage systems for improving rice lands productivity in eastern India: Opportunities and challenges. On farm reservoir systems for rainfedrice lands, S. I. Bhuiyan, ed. International Rice Research Institute, Manila, Philippines 105—125.

Panigrahi B (2011) Irrigation system engineering. New India Publishing agency.

Panigrahi B, Panda SN (2003) Optimal sizing of on farm reservoirs for supplemental irrigation. *J Irrig Drain Engg* 129 (2) : 117—128.

Sahoo BC, Panda SN, Panigrahi B (2009) Reduction of evaporation loss from the on-farm reservoir through biological shading. Int. Conf. on An International Perspective on Environmental and Water Resources at AIT, EWRI and AIT, Bangkok, Thailand.

Sahoo BC, Panda SN, Panigrahi B (2010) Modeling Evaporative Water Loss from the On-Farm Reservoir with Biological Shading. *J Hydrol Engg* 15 : 544—553.

Saxena K, Tiwari KN (1988) Water harvesting ponds capacity calculation and design. *Ind J Power River Valley Develop* 38 (1, 2) :12—16.

Setiawan BI, Saleh E, Nurhidayat Y (1998) Pitcher irrigation system for horticulture in dry lands. Proceedings of Water and Land Resources Development and Management for Sustainable Use. Vol. II-A. The Tenth Afro-Asian Regional Conference. ICIDCIID, INACID, Denpasar- Bali, Indonesia, pp 10.

Sharada VN, Shrimati SS (1994) Water harvesting and recycling in northern hill regions. *Ind J Soil Conserv* 22 (1, 2) : 84—93.

Siyal AA, Genuchten MT, Skaggs TH (2009) Performance of Pitcher Irrigation System. *Soil Sci* 174 :312—320.

Soomro AA (2002) Viability of pitcher irrigation. Daily Dawn Karachi. 6th May issue. http://www.dawn.com/2002/05/06/ebr12.htm.

Srivastava RC (2001) Methodology for design of water harvesting system for high rainfall areas. *Agricult Water Manag* 47 (1) : 37—53.

Stein TM (1997) The influence of evaporation, hydraulic conductivity, wallthickness and surface area on the seepage rates of pitchers for pitcherirrigation. *J Appl Irrig Sci* 32 (1) : 65—83.

Syamsiah I, Fagi SAM, Bhuiyan SI (1994) Collecting and and conserving rainwater to alleviate drought in rainfed rice lands of Indonesia. On-farm reservoir systems for rainfed rice lands, IRRI, Los Banos, Laguna Philippines 141—152.

Ventura F (2001) Model for estimating evaporation and transpiration from row crops. *J Irrig Drainage Engg* 127 (6) : 333—345.

Verma HN (1981) Water harvesting for life saving irrigation of rainfed crops in the sub-mountain region of Punjab. *J Agricult Engg Res* 18 (3 and 4) : 64—72.

Wardana IP, Sasa IJ, Fagi SAM, Bhuiyan SI (1996) On-farm reservoir system: Management requirements and impact on productivity. Rainfed Lowland Rice Research Consortium In-HouseMidterm Review, IRRI, Philippines 1—18.

Watts PJ (2005) Scoping study-Reduction of evaporation from farm dams. Final Report to the National Program for Sustainable Irrigation, Feedlot Services Australia Pty. Ltd., Toowoomba, Australia 1—79.