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Manika Gupta

N.K. Garg

Prashant K. Srivastava

Tanvir Islam

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INTEGRATION OF TRMM RAINFALL IN NUMERICAL MODEL FOR PESTICIDE PREDICTION IN SUBTROPICAL CLIMATE

MANIKA GUPTA (1), N.K.GARG (1), PRASHANT K SRIVASTAVA (2,3), TANVIR ISLAM (4,5)
(1): Department of Civil Engineering, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, 110016, India
(2): Earth System Science Interdisciplinary Center, University of Maryland, Maryland, 20740, USA
(3): NASA Goddard Space Flight Center, Greenbelt, Maryland, 20771, USA
(4): NOAA/NESDIS Center for Satellite Applications and Research, College Park, 20740, USA
(5): Cooperative Institute for Research in the Atmosphere, Colorado State University, Colorado, 80523, USA

ABSTRACT
Rain gauge data in developing countries are usually very limited, which constrains most of the hydrological modelling applications. The satellite based rainfall estimates could be a promising choice and hence can be used as a surrogate to ground-based rainfall. However, the usefulness of these products needs to be evaluated for hydrological application such as for pesticide predictions. The present study compares the contaminant transport simulation with the utilization of Tropical Rainfall Measuring Mission (TRMM) rainfall compared with rain gauge data from the field site. Through this study, transport trends of the pesticide, Thiram, a dithiocarbamate, at different time and depth in the fields under real field conditions for the wheat crop were compared to the numerical simulations using HYDRUS- 1D with the input of daily rainfall from the TRMM up to 60 cm vertical soil profile with the intervals of 15 cm. The simulated soil moisture content using ground based rainfall and TRMM derived rainfall measurements indicate an agreeable goodness of fit between the both. Further, comparison of the model to measured field data of pesticide movement indicates that the modelling approach can provide reliable and useful estimates of the mass flux of water and non-volatile pesticide in vadose zone in absence of ground based measurements of soil pesticide. Thus, the satellite-based rainfall products could also be useful for policy makers and planners while controlling inappropriate pesticide application under saturated and deficit soil moisture conditions.

INTRODUCTION

Modern crop productivity requires the use of pesticides resulting in maximum crop yields. In this context, to control the diseases the use of pesticides is important [1]. However, presence of pesticide residue in the soil could damage the succeeding sensitive crops [2]. The risk of environmental pesticide contamination to soils is not well understood due to data limitations. Many of these compounds persist in soil [3]. Accordingly, intensive sampling is required to achieve a reliable quantification of pesticide pollution. Also, observational soil moisture data, a key variable in hydrologic cycle and contaminant transport, are still rare, which strongly limits our understanding of ongoing changes. Therefore an approach to reduce the environmental pollution due to pesticide persistence and mobility in agricultural fields must be based on understanding the relationship in a modeling framework. Inaccurate estimation of rainfall, which being one of the important component in soil water balance, can affect the quantification of soil moisture [4, 5]. Conventionally, rain gauges and gravimetric based soil moisture measurements are being used for decades to estimate precipitation and soil moisture over a region [6]. However, maintenance and establishment of good gauge density network in the remote areas has always been a challenge [5] and results in unavailability of calibration and validation datasets [7]. The latest remote sensing product such as Tropical Rainfall Measuring Mission, (TRMM) provides opportunities for optimum predictive modelling at a local/regional or global scales [8].

The use of numerical model like HYDRUS 1D [5, 9] with the satellite (TRMM) based rainfall as an input data to simulate soil moisture and pesticide residue on a temporal and spatial scale could be an useful approach for the regions with scarce rain gauge network. In this study, numerical simulations were performed using the TRMM rainfall after the field experiments were conducted under different irrigation treatments to ascertain the agreement in predicting the spatial and temporal trends of Thiram in the vadose zone.

METHODOLOGY

Study area

The experimental field was located in an agricultural field at Saliyar village, Roorkee, (29° 51' 0" N latitude and 77° 53' 0" E Longitude), India. The study site is under a humid sub-tropical climatic zone. Wheat along with Thiram, used in wheat seed protection was chosen for the field experiments. The location of the field site is shown in the following Fig.1

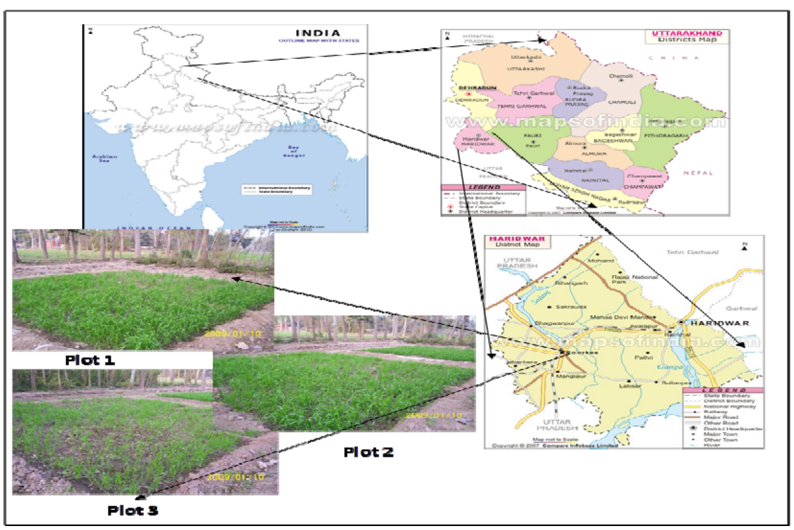

Figure 1 Location map of study area with study sites

Field experiments

Wheat chosen for the field experiments was cultivated in plots (5m x 5m) with Thiram applied at the rate of 0.8 kg ha^{-1}. The soil textural class was silt loam. Bulk density was obtained for the undisturbed soil cores for each 15 cm depth. The soil-water retention curves were determined for the disturbed samples using pressure plate apparatus and saturated hydraulic conductivity (*Ks*) was determined using the constant head permeameter method. The average characteristics of the soil for the three plots along with Meteorological data are presented elsewhere [9, 10]. Due to the decreasing water availability in many parts of the world, water efficient irrigation is necessary to increase agricultural productivity. The three wheat plots were given different irrigation treatments to understand the fate of Thiram under different soil water conditions. An efficient irrigation scheduling relies on soil water content data to quantify the amount of soil water and thus to properly define irrigation depth. The applied irrigation depth is a supplement to rainfall data being considered to simulate the soil moisture storage. The irrigation treatments consisted of irrigation scheduling based on maximum allowable depletion (MAD) of available soil water (ASW) criteria, taken as 25%, 50% and 75% for plot1, plot2 and plot3, respectively. The percentage depletion of available soil water in the effective root zone is estimated by using the following Eq. (1) [11]:

$$Depletion\% = 100 \times \frac{1}{n} \sum_{j=1}^{n} \frac{\theta f_j - \theta_j}{\theta f_j - \theta w_j} \quad (1)$$

Where, n is the number of layers of the effective rooting depth used for the soil moisture sampling, θ_f is the volumetric soil water content at field capacity of the jth layer (cm^3 cm^{-3}), θ_j is the volumetric soil water content in jth layer before irrigation (cm^3 cm^{-3}) representing the modelled soil moisture or in-situ data obtained for the soil depths and θ_w is the volumetric soil content at wilting point of the jth layer (cm^3 cm^{-3}). The depth of water to be applied to reach the field capacity at particular, MAD is calculated by the following Eq. (2) [12]:

$$d_{irr} = \frac{1}{IRE} \times \sum_{j=1}^{n} \frac{MAD(\theta f_j - \theta w_j) \times Rz_j}{100} \quad (2)$$

Where, d_{irr} is the depth of irrigation water to be applied (cm), R_{zi} is the depth of jth soil layer within the effective rooting depth (cm) and *IRE* is the irrigation efficiency (%), being assumed to be nearly 80% during surface irrigation resulting from on field and transportation losses. The depth of the root zone varies in time according to plant's growth cycle.

Satellite data

A series of quasi-global, near-real-time, TRMM-based precipitation estimates is obtained from http://mirador.gsfc.nasa.gov. The level three data product that is TRMM-3B42, which is used in this study is a 3- hourly 0.25° product based on multi-satellite precipitation analysis with grid over the latitude band 50 ° N-S [13].

Numerical simulations

The transport of Thiram was numerically simulated using HYDRUS-1D [14], which numerically solves both the Richards' equation for soil water flow dynamics.

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K(h)\left(\frac{\partial h}{\partial x}\right)\right] - S \quad (3)$$

Where, h is the water pressure head (cm), θ is the volumetric water content (cm^{3}cm^{-3}), t is time (days), x is the spatial coordinate (cm) (positive upward), K is the unsaturated hydraulic conductivity (cm day^{-1}) and S is the sink term (cm^3 cm^{-3} day^{-1}), representing the root water extraction rate for which the model, Feddes, et al., [15], is used. The Fickian-based convection–dispersion equation is used for the solute transport.

$$\frac{\partial C_T}{\partial t} = \frac{\partial \theta c}{\partial t} + \frac{\partial \rho_b s}{\partial t} = \frac{\partial \left(\theta D^w \frac{\partial c}{\partial x} \right)}{\partial x} - \frac{\partial qc}{\partial x} - \mu_w \theta c - \mu_{so} \rho_b s \tag{4}$$

Where,

$$s = K_d c \tag{5}$$

C_T is the total solute concentration in units of mass per volume of soil (mg cm^{-3}), c and s are solute concentrations in the liquid (mg cm^{-3}) and the solid (mg mg^{-1}) phases respectively; q is the volumetric flux density (cm day^{-1}), μ_w, μ_{so} are first-order rate constants for solutes in the liquid and solid phases (day^{-1}) respectively; ρ_b is the soil bulk density (g cm^{-3}), D^w is the effective dispersion coefficient (cm^2 day^{-1}) for the liquid phase, K_d is the distribution coefficient (cm^3 mg^{-1}), *w, so*, correspond with the liquid and solid phases respectively. The van Genuchten model [16], along with K_s is used to determine the unsaturated hydraulic conductivity (K). The non linear unsaturated flow Eq. (3) is solved using an explicit expression between the dependent variable h and the nonlinear terms K and θ. The following closed form θ-h relationship is used,

$$\theta = \begin{cases} \theta_s & \text{h} \geq 0 \\ \theta_r + \dfrac{(\theta_s - \theta_r)}{\left[1 + (\alpha h)^n\right]^m} & \text{h} < 0 \end{cases}, \quad m = 1 - 1/n \tag{6}$$

Where, θ_s is saturated soil water content (cm^3 cm^{-3}); θ_r is residual soil water content (cm^3 cm^{-3}) and θ is soil water content (cm^3 cm^{-3}) at soil matrix potential (h). n and α are curve fitting SHPs. The van Genuchten [16] uses the statistical pore size distribution model [17] along with Eq. (6) and determined K to yield the K-h relationship,

$$K = \begin{cases} K_s & \text{h} \geq 0 \\ K_s \dfrac{\left\{1 - (\alpha h)^{n-1}\left[1 + (\alpha h)^n\right]^{-m}\right\}^2}{\left\{1 + (\alpha h)^n\right\}^{ml}} & \text{h} < 0 \end{cases} \tag{7}$$

Where l is the shape parameter, accounting for the tortuosity in the soil and is not found to be a sensitive parameter [18]. Thus, the suggested value has been assumed i.e. 0.5 [19].

Model performance

Nash–Sutcliffe modelling efficiency (E) [20] was used to assess the level of agreement between the simulated and measured pesticide concentrations.

RESULTS AND DISCUSSION

Temporal and spatial water content simulation

The average soil water contents were experimentally determined and were numerically simulated with both rain gauge data and TRMM based rainfall for all the three plots from the day of sowing of wheat. The R^2 of simulated with rain gauge data and measured soil water contents at different depths varied between 0.77 and 0.90 [9]. The NSE is given in Table 2 to demonstrate the performance of the model in simulating soil water content with ground based rainfall and TRMM derived rainfall for the depths 0-60cm for the three irrigated plots. The rainfall doesn't affect simulation in case of plot1 which is under 75% irrigation and the efficiency is above 70% for all the four depths. However, with reduced irrigation of 50% and

25%, there is drastic decrease in NSE. The performance statistics shows a slightly poor prediction for TRMM rainfall under water limiting conditions. The performance using the TRMM derived rainfall goes down in water limiting conditions during the later part of the study as higher rainfall estimations were obtained compared to the station data [5].

Table 1. NSE for the simulated soil water content using ground-based and TRMM based rainfall

		NSE			
	Soil depth (cm)	0-15	15-30	30-45	45-60
Plot 1	Ground based	0.91	0.69	0.85	0.71
	TRMM based	0.69	0.63	0.49	0.43
Plot 2	Ground based	0.79	0.77	0.84	0.85
	TRMM based	0.49	0.36	0.20	0.78
Plot 3	Ground based	0.78	0.67	0.83	0.76
	TRMM based	0.47	0.40	0.30	0.83

Thiram simulations

The initial concentration of Thiram determined before the Thiram application in soil in all the plots was found to be zero. Fig.2 (a-c) summarizes the measured and simulated both with ground based and TRMM rainfall, temporal distribution of the fungicide residual of all the three plots till the end of the crop period at different depths. It can be further observed that primarily Thiram residue is confined to 0-15 cm depth, being categorized as non-polar compound and since no residue was found beyond 30 cm the plots represent the data for the 0-30 cm depth. The simulated Thiram breakthrough curves (BTCs) are in good agreement with measured BTCs for the different irrigation treatments with efficiencies of the model in the range of 0.75-0.85 for the depth 0-15 cm in all the plots when simulated using both ground based and TRMM based rainfall. In the experimental observations, Fig.2(a-c), within 20 days of pesticide application less than 50% of the initially applied pesticide remained in 0-15 cm depth in plot 1 and plot 2. In plot 3, the pesticide was reduced to 50% at the end of 25 days in 0-15 cm depth while in plot 1 and plot 2 it was reduced to 30% of the initially applied pesticide. At the depth of 15-30 cm, traceable concentration of initially applied concentration was detected at the end of 30 days in all the three plots. In plot 1, even with two applications of irrigation depths and one rainfall event, only traceable concentration is found in 15-30 cm depth. Thus, frequent irrigations or rainfall can lead to mobility of Thiram to lower depths but with negligible concentrations before its complete degradation. However, in spite of higher irrigation in plot 1, Thiram remained only in traceable limits in 15-30 cm depth. It may be attributed to low solubility of Thiram and high adsorption coefficient. The degradation of fungicide has been found, both in experiments and numerical simulations, not to be much influenced by soil water content. The rate of Thiram decomposition in the depth 0-15 cm is nearly similar in all the three plots with slight slower rate in plot 3, which was under the lowest water flux condition. The pesticide flux was found to be similar as with the ground based rainfall. However, in water limiting condition of the third plot there is faster degradation of Thiram as TRMM rainfall incorporated in HYDRUS 1D over estimated the soil moisture. Also, since the pesticide was mainly confined in the surface layer where the efficiencies of soil water content simulation were better than for the lower depths, the

TRMM estimated higher rainfall did not affect much the pesticides simulations. It is thus, concluded that for more improved pesticide residue prediction especially if the pesticide is mobile, there is a need of more efficient algorithms for an improved estimate of rainfall.

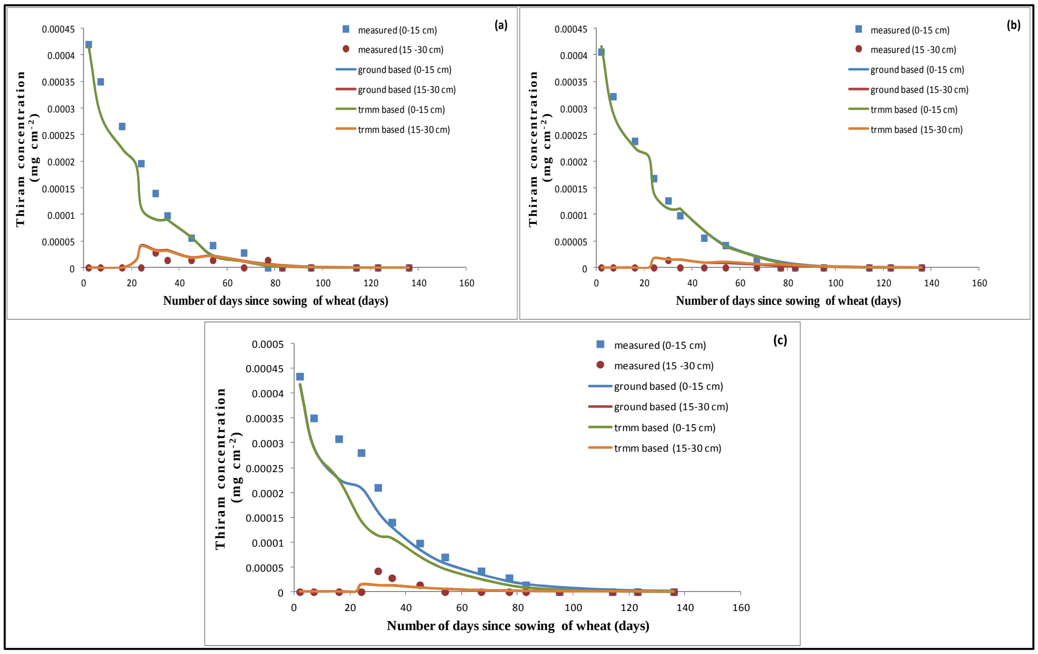

Figure 2 Pesticide residue: (a) Plot 1, (b) Plot 2 and (c) Plot 3

CONCLUSION

This study provides a first-time comprehensive model and TRMM evaluation for the performance of the rainfall input data for agricultural application. It is observed that TRMM rainfall provides soil moisture with some over estimation for the lower depths of soil for water limiting conditions. However, in total the prediction through HYDRUS 1D using the TRMM rainfall is promising in absence of any ground based measurements. The pesticide flux was found to be similar as with the ground based rainfall. In water limiting condition of the third plot there is faster degradation of Thiram as TRMM rainfall incorporated in HYDRUS 1D over estimated the soil moisture. It is thus, concluded that for more improved pesticide residue prediction, there is a need of more efficient algorithms for an improved estimate of rainfall. We believe, this study will provide agronomist with valuable information on pesticide residue prediction. Further investigation of this potentially important data source by the scientific community is recommended so that useful understanding and knowledge could be disseminated.

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