Estimation of runoff at Glen in the Free State Province of South Africa

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Abstract

Reliable runoff estimation is important for simulating long-term crop yields in semi-arid areas. It requires reliable data including soil and rainfall characteristics. This paper aims to simulate runoff for each rainfall event on the Glen/Tukulu ecotope, in central South Africa, using annual runoff data measured over 18 years (1937 to 1955) on a conventional tilled soil, annually planted to maize, and a bare untilled soil. Runoff calculated for these two treatments provides information needed to simulate long-term crop yields using conventional tillage and in-field water harvesting. The PutuRun model was used to stochastically disaggregate daily rainfall data into shorter duration rainfall intensities and to simulate runoff for each rainfall event during a particular season. The simulated runoff data were summed for each season and compared with the observed annual runoff values during the respective years to evaluate the performance of the model. The model was calibrated using half of the data and validated using the rest. Calibration was carried out by running the model a number of times with a different set of input parameter values, until acceptable results were obtained. The following statistical results were obtained for the validation tests: for the maize plots index of agreement (d) = 0.85, root mean square error (RMSE) = 24 mm, mean absolute error (MAE) = 18 mm, systematic RMSE (RMSEs) = 16 mm, unsystematic RMSE (RMSEu) = 17 mm, and coefficient of determination (r^2) = 0.58; and for the bare plots d = 0.90, RMSE = 51 mm, MAE = 48 mm, RMSEs = 13 mm, RMSEu = 49 mm, and r^2 = 0.74. It is concluded that the PutuRun Model can be used with reasonable confidence after calibration to simulate long-term runoff on conventionally tilled, and bare untilled plots on the Glen/Tukulu ecotope using daily rainfall data. This procedure is expected to yield satisfactory results on other ecotopes with similar soil, slope, and rainfall characteristics.

Keywords: Glen, modelling, PutuRun, runoff

Introduction

In arid and semi-arid areas long-term modelling of agricultural productivity is a valuable tool in agricultural research, land evaluation and production planning. This requires reliable estimates of the components of the soil water balance: rainfall, runoff, deep drainage and evapotranspiration (Jury et al., 1991). Runoff is particularly important for comparing crop yields using conventional tillage and in-field rain-water harvesting (IRWH). Runoff is considered a loss in conventional tillage and can be made into a profit using IRWH (Hensley et al., 2000). It is, however, often difficult to estimate runoff reliably. Bennie et al. (1998), after many years of research on the soil water balance, admitted that much more research is needed to estimate runoff reliably. Runoff estimation is complex because it is affected by several factors including rainfall intensity, slope of the land, initial and final infiltration rates, roughness of the surface, initial soil water content, crust formation, land use, and land cover (Morin and Benyamini, 1977; Allen et al., 1998). Bennie et al. (1998) indicated that, if surface storage is ignored, runoff during a rainstorm normally starts to take place when the rainfall intensity exceeds the infiltration rate of the soil. Accurate estimation of runoff therefore requires rainfall intensity (Pi) data and reliable data for the factors mentioned. Where Pi is not available daily rainfall has to be used. Seeking a relationship between daily rainfall and runoff is therefore important, making the results of long-term runoff experiments particularly valuable. This is especially true in semi-arid areas where a considerable fraction of annual rainfall occurs as high-intensity thunderstorms, and where soils tend to crust. Both these conditions occur at Glen.

In a study on a red loamy fine sand surface soil with a 5% slope at Glen (Glen/Tukulu ecotope) with a mean annual rainfall (MAR) = 545 mm, Du Plessis and Mostert (1965) measured runoff and soil loss for 18 years (1937 to 1955) on runoff plots. They reported mean annual runoff of 8.5% and 31.9% of the mean annual rainfall from the plots under continuous maize cultivation, and from the untilled, crusted bare plots respectively. In a study under similar soil and slope conditions to those of Du Plessis and Mostert (1965), over a period of 27 years at Pretoria (MAR = 730 mm), Haylett (1960) reported runoff of 26.7% and 49.4% of the mean annual rainfall from continuous maize and from untilled, crusted, bare soil respectively.

Gibbs et al. (1993) reported annual runoff measurements from bare plots at Cedara over 10 years. The soil was classified as an Inanda form with a clay texture. The correlation between annual runoff and annual rainfall was poor (r^2 = 0.44). Mean annual runoff was 15% of the mean annual rainfall. These values are considerably different from those obtained at Glen and Pretoria. The following are probable reasons: Firstly, rainfall at Cedara includes a considerable amount of soft rain, and secondly, because the Inanda soil is highly weathered, high in clay and high in organic matter, very little crusting is expected, and the final infiltration rate is expected to be relatively high. Both these factors will reduce runoff.

Hensley et al. (2000) found that the final infiltration rate (I_f) on two ecotopes at Glen (Glen/Bonheim and Glen/Swartland) was approximately 6 mm·h^{-1}, and that runoff occurred on a crusted flat

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