Stochastic Physical Ecohydrologic-based Model for Estimating Irrigation Requirement

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Background

- In semi-arid and arid regions, the most important part of irrigated cultivation may be done during the wet season to benefit more from rainfall for supplying crop water requirements. Therefore rainfall uncertainty should be taken into account in irrigation management.
- Irrigation management needs two essential parts:
  1) planning in which long term predictions of irrigation requirement is employed and
  2) scheduling in which short term forecasts of irrigation requirement is necessary.
- Deterministic physically-based numerical methods (*Smajstrla and Zazueta* 1987), stochastic time series modeling (*Gupta and Chauhan* 1986), and stochastic physically-based models for estimating expected value of irrigation requirement (*Vico and Porporato* 2010) have been proposed for estimation of irrigation water requirement in past.

Goal

- Based upon a stochastic soil moisture model, expressions for probability density function of seasonal irrigation water depth under contrasting micro and traditional irrigation technologies are derived, taking an analytical modeling approach via stochastic dichotomous and renewal processes.

Stochastic Soil Moisture Dynamics

- The soil moisture, at daily time scale, is modeled as a piecewise deterministic process driven by white shot noise of effective rainfall (*Rodriguez-Iturbe et al.* 1999), where the active soil is treated as a reservoir with an effective storage capacity that is filled by intermittent effective rainfall pulses of random depth and demand-based irrigation events. Also soil water losses occur via evapotranspiration, deep percolation, and surface runoff.
- A scheme of demand-based irrigation (*Vico and Porporato* 2011) which can distinguish between often-employed methods including the traditional irrigation and the modern micro irrigation techniques is utilized. The scheme provides a framework for considering a range of irrigation strategies from the rainfed agriculture to the stress-avoidance irrigation, covering different levels of deficit irrigation.

Dichotomous Markov Process for Micro-irrigation

- Based upon the stochastic soil moisture dynamics, the daily rate of irrigation requirement (per unit area) in the case of micro-irrigation can be modeled as a stochastic process which takes just two values. While during irrigation phases, when the soil moisture is at intervention point, daily rate of irrigation requirement is fixed and equals actual evapotranspiration at intervention point, it vanishes when an effective rainfall event takes place and irrigation is not started till soil moisture reaches the intervention point again.
- Assuming stochastic steady-state condition for the soil moisture process during the growing season, the described two-valued process of micro irrigation could be modeled by a dichotomous process.
- To derive probability density function (PDF) of the seasonal irrigation requirement, we need to assess another process which is time integral of the dichotomous process. The PDF could not be easily derived for a general condition, but there are some derivations for some specific conditions; we have derived the PDF for the case in which one of the values of the dichotomous process equals zero.

Renewal Process for Traditional Irrigation

- Traditional irrigation at daily time scale could be considered as concentrated delivery of fixed depth when soil moisture level reaches to the intervention point
- Under stochastic rainfall condition, the traditional irrigation applications could be modeled as a marked point process with constant marks equals to depth of each irrigation application.
- The point process is not a Poisson process, but it is a renewal process with semi-exponentially distributed intervals.
- Probability mass function of the seasonal irrigation water requirement under traditional irrigation was derived.

Figure 1

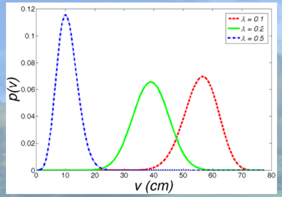


Figure 2

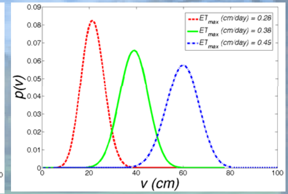


Figure 3

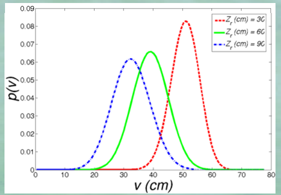


Figure 4

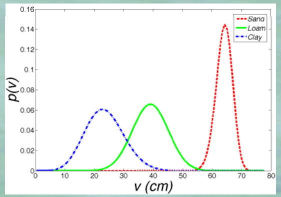
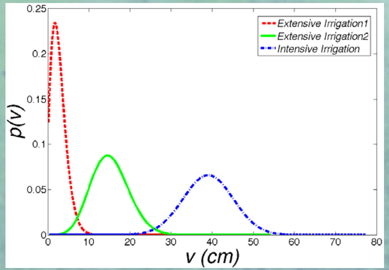


Figure 5



Results

- Figures show PDF of seasonal irrigation requirement (SIR) under micro-irrigation.
- Figures 1 shows sensitivity of the SIR to climate parameter, mean frequency of daily rainfalls (λ). The more is the value of λ, the wetter will be the climate. Increase in the value of the parameter causes reduction in SIR. For value of λ from 0.1 to 0.2 (day^{-1}) the SIR uncertainty (evaluated simply by the variation range) increases gradually, while for the values from 0.2 to 0.5 a significant decrease in the SIR uncertainty is observed. Moreover, variation in this parameter leads to a significant change in expected value of SIR.
- Increase in evapotranspiration demand causes increases in both SIR value and the uncertainty of SIR (Figure 2).
- The shallower is the root, the bigger SIR value and the less uncertainty of SIR will be (Figure 3).
- Increase in soil grain size from clay to sand leads to an increase in SIR value and a reduction in SIR uncertainty (Figure 4).
- Figure 5 compares PDF of SIR for irrigation policies including two levels of the deficit (extensive) irrigation and the stress-avoidance (intensive) irrigation. It is observed that under intensive irrigation, both the value and the uncertainty of SIR are greater than those of the extensive irrigation. It is worth mentioning that under the case of Extensive Irrigation1 (performed by taking lower values for intervention point of irrigation), the crop experiences more water stress compared to the case of Extensive Irrigation2 (performed by taking upper value for intervention point of irrigation).

References

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