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Modeling soil water contents, potato growth and yield with SWACROP model in Punjab, India

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ABSTRACT

The SWACROP model (SWAP 93 version) was used for dynamic simulation of growth and yield of potato (*Solanum Tuberosum* L.) crop under three dates of sowing and three irrigation regimes. Potato variety, Kufri Chandramukhi was grown for two crop seasons of autumn 2003-04 and spring 2004 in the sub-tropical semi-arid climate of Ludhiana, Punjab, India. Weather (temperature, rainfall, solar radiation), soil (root-zone soil moisture) and crop (leaf area index, tuber yield) data were recorded during both crop seasons. The model was calibrated for coefficients in the "Van Genutchen" and "leaf area index-soil cover" equations using the treatment data for optimum date of sowing (recording highest yield in each season) and receiving maximum irrigation frequency. The simulated soil water content in the root zone followed the field time-trends and were also in close agreement with observed data. Compared to actual field observations, the leaf area index was predicted within -10 to +19% in autumn crop season and within -7 to +21% in the spring crop season while tuber yields were predicted within -13 to +9% in the autumn crop season and -28 to +11% in the spring crop season by the model.

Keywords: Crop modeling; Dynamic simulation; Potato; SWACROP; SWAP 93; Soil moisture simulation

Potato (*Solanum Tuberosum L.*) crop is the major vegetable crop grown in north-west India and in Punjab it occupies nearly 70,000 ha which is nearly one-half of the total area under vegetable crops in the state (Anonymous, 2002). Climate of the region is sub-tropical with hot summers and cold winters. The crop is planted in September/October (as autumn crop) and in January (as spring crop) and harvested 90-110 days after sowing. Since field experiments to evaluate agronomic practices are very costly and time consuming, various dynamic crop simulation models have been developed in recent years to simulate growth and yield of various crops. Such models can help evaluate agronomic practices for maximizing crop yields and also predict crop productivity. Various models specific to potato crop include SWACROP (Feddes *et al,* 1978; Belmans *et al,* 1983), POTATO (Ewing *et al,* 1990), Sim ISP (Singh *et al,* 1993), LINTUL-POTATO (Kooman and Harverkort 1995), Climate

Potato (Schapendonk and Pot 1995), SIMPOTATO (Hogdes 1992) and SUBSTOR (Ritchie *et al*, 1996).

SWACROP model has been tried in different locations around the world (Mahdian and Gallichand 1996, Ghahrerman 1999), but no work has been reported so far on application of potato growth models in Punjab/India. Hence the present study was undertaken to evaluate the performance of SWACROP model (SWAP 93 version) for simulating potato growth and yield as well as soil water contents under semi-arid conditions of Punjab, India.

MATERIALS AND METHODS

Field experiments were conducted at Ludhiana, India (30° 54'N, 75° 48'E and 247 m above mean sea level) with potato cultivar, Kufri Chandramukhi sown on three sowing dates (D_1=30 September, D_2=15 October and D_3=28 October) during autumn crop season 2003-04 and (D_1=19 January, D_2=30 January and D_3=12 February) in spring crop season 2004. Three irrigation regimes (I_1, I_2 and I_3 corresponding to IW:CPE=0.5, 0.75 and 1.5 respectively) were studied based on depth of irrigation water (IW) and cumulative pan evaporation (CPE) under each date of sowing. Seed potato tubers were sown on ridges 60 cm apart with 20 cm plant-to-plant spacing on a loamy sand soil with an organic carbon content of 0.4%. The crop received fertilizers at the rate of 188 kg N, 100 kg P_2O_5 and 125 kg K_2O per ha. Irrigations of 50 mm were scheduled as per treatment requirements. The crop was kept free of weeds through manual weeding and free of pests by spraying recommended pesticides. Observations on soil water content (0-60 cm root zone) were made gravimetrically and leaf area index (LAI) were measured at 15 days interval. Tuber yield was recorded at maturity.

Model description

Feddes *et al,* (1978) developed SWATR (Soil Water Actual Transpiration Rate) model to describe the transitional flow of water in a heterogeneous soil-root system which is affected by groundwater. In the extended version, SWATRE, developed by Belmans *et al.* (1983), a different numerical solution was used with a possibility of using improved boundary conditions. Wesseling and Van Den Broek (1983) made further improvements to this model. Feddes (1984) incorporated two models of SWATRE and CROPR in one model called SWACRO, which could simulate actual growth and development of Potato crop. Wesseling *et al.* (1991) later modified SWACRO model to give the SWACROP model. The present study has used SWAP 93 version of the SWACROP model.

SWACROP is a one-dimensional model, which solves the Richard's equation for vertical flow of water in heterogeneous soil-root system. Rate of dry matter increase for a crop with optimum nutrient conditions is calculated using CROPR (CROP Production) sub-routine developed by Feddes *et al.* (1978). In this sub-model, growth rate is a function of transpiration rate. Three evapotranspiration equations,

Table 1: Calibrated values of SWACROP model (Van Genutchen and LAI-SC coefficients) for autumn and spring crop seasons.

Coefficient	Autumn Season	Spring season
θr	0.04	0.04
θs	0.36	0.36
n	1.35	1.30
m	0.26	0.27
a	0.05	0.05
a_1	1.50	1.50
a_2	1.75	1.75
a_3	0.90	0.80

Van Genutchen Coefficients:
θr – residual soil water content
θs –saturated soil water content
n and m are constants depending on soil texture
LAI-SC Coefficients:
a, a_1, a_2 and a_3 are constants in the Leaf area-Soil cover relationship.

namely, Penman (1948), Priestly-Taylor (1972), and Montieth-Rijtema (1965) were studied.

Model calibration

The SWACROP model was calibrated for the experimental cultivar with data of optimum sowing date and non-water stress treatment (namely, D_3I_3 in autumn and D_1I_3 in spring crop season) by adjusting Van-Genutchen (1980) equation coefficients of θr, θs, n and m as well as "LAI-SC" equation coefficients of a, a_1, a_2 and a_3. The value of coefficient was either increased or decreased such that there were least differences in simulated and the measured tuber yield. The chosen values of these calibration coefficients are given in Table 1.

Model validation

The SWACROP model was validated for soil water content during the autumn crop season with data from remaining treatments (excluding those used in calibration of the model). These treatments comprised of D_1 and D_2 dates of sowing and I_1 and I_2 moisture regimes.

The model was validated for leaf area index and tuber yields during both the autumn and spring crop seasons with data from remaining treatments (excluding those used in calibration of the model). These treatments comprised of D_1 and D_2 dates of sowing in autumn crop season and D_2 and D_3 dates of sowing in the spring crop season and I_1 and I_2 moisture regimes in both autumn and spring crop seasons. The simulated growth/yield parameters were compared with the field observations and the deviations between them were assessed for testing the applicability of the model.

RESULTS AND DISCUSSION

Root zone soil water content

The comparison between simulated and actual soil water content during both crop seasons revealed that in general the model simulated the time-trends in soil water contents similar to measured water content trends with time for dates of sowing and irrigation treatments, and further the simulated values were in close agreement with the measured values (Fig. 1). The

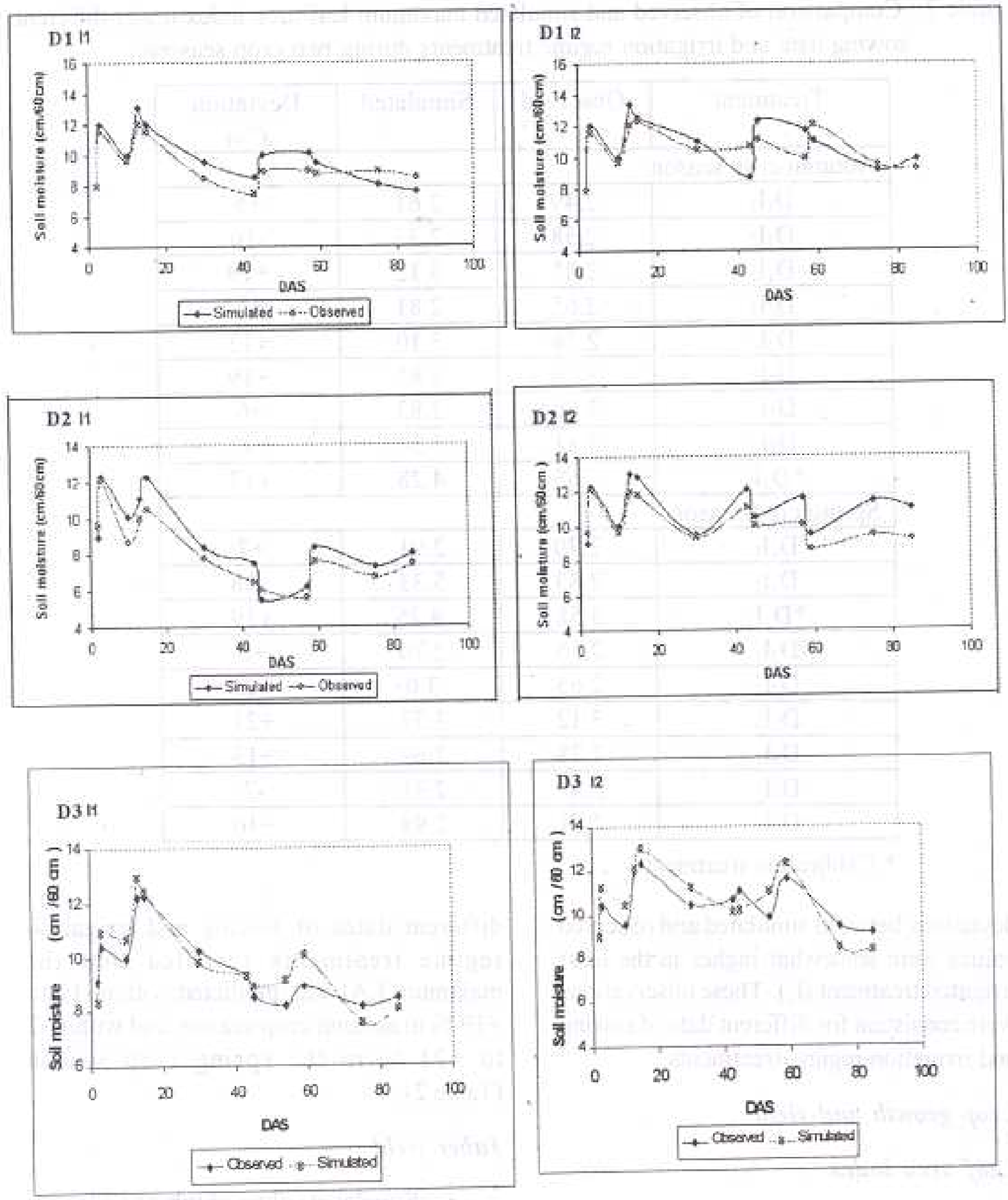

Fig 1 : Comparison of observed and simulated soil water content At I_1 and I_2 moisture regimes under three dates of sowing (Autumn 2003-04)

Table 2 : Comparison of observed and simulated maximum leaf area index under different sowing date and irrigation regime treatments during two crop seasons.

Treatment	Observed	Simulated	Deviation (%)
Autumn crop season			
D_1I_1	2.49	2.61	+5
D_1I_2	2.58	2.33	-10
D_1I_3	2.85	3.12	+19
D_2I_1	2.65	2.81	+6
D_2I_2	2.76	3.10	+12
D_2I_3	3.23	3.85	+19
D_3I_1	2.68	2.83	+6
D_3I_2	2.81	3.30	+17
*D_3I_3	3.65	4.28	+17
Spring crop season			
D_1I_1	2.70	2.91	+7
D_1I_2	2.83	3.33	+18
*D_1I_3	3.58	4.25	+19
D_2I_1	2.55	2.70	+6
D_2I_2	2.63	3.0	+15
D_2I_3	3.12	3.77	+21
D_3I_1	2.38	2.69	+13
D_3I_2	2.49	2.31	-7
D_3I_3	2.71	2.98	+10

* Calibration treatment

deviations between simulated and observed values were somewhat higher in the least irrigated treatment (I_1). These observations were consistent for different date of sowing and irrigation regime treatments.

Crop growth and yield

Leaf area index

A comparison of measured and simulated leaf area index (LAI) under different dates of sowing and irrigation regime treatments revealed that the maximum LAI was predicted within -10 to +19 % in autumn crop season and within -7 to +21 % in the spring crop season (Table 2).

Tuber yield

Simulated values of tuber yield using three choises of evapotranspiration equations (Penman; Priestly–Taylor; and Montieth–

Table 3: Observed and simulated tuber yields with SWACROP model using three choices of evapotranspiration functions during two crop season

Treatment	Observed (t ha^{-1})	Simulated (t ha^{-1})			Deviation (%)		
		Penman	Priestly-Taylor	Monteith-Rijtema	Penman	Priestly-Taylor	Monteith-Rijtema
Autum crop season							
$D_1 I_1$	14.1	15.4	15.3	12.3	+9	+7	-13
$D_1 I_2$	18.5	18.9	19.1	17.6	+2	+3	-5
$D_1 I_3$	23.6	21.2	24.2	22.2	-10	+2	-6
$D_2 I_1$	15.8	16.5	14.5	13.1	+4	-6	-4
$D_2 I_2$	19.4	18.8	18.6	18.6	-4	-4	-4
$D_2 I_3$	26.6	25.2	27.3	25.4	-5	+2	-5
$D_3 I_1$	21.2	20.15	22.5	20.1	-5	+6	-5
$D_3 I_2$	28.5	27.4	28.65	25.4	-5	0	-7
*$D_3 I_3$	32.9	30.8	33.4	31.2	-6	+2	-5
Spring crop season							
$D_1 I_1$	16.5	14.65	13.9	13.1	-11	-16	-21
$D_1 I_2$	20.7	18.1	17.2	16.8	-13	-17	-19
*$D_1 I_3$	28.4	25.7	25.0	24.5	-10	-12	-14
$D_2 I_1$	12.8	10.1	09.8	9.2	-21	-23	-28
$D_2 I_2$	17.1	15.2	14.6	14.2	-11	-15	-18
$D_2 I_3$	22.5	19.1	18.9	18.1	-15	-16	-20
$D_3 I_1$	10.1	11.2	8.3	7.65	+11	-18	-24
$D_3 I_2$	15.4	16.7	12.6	11.9	+8	-5	-10
$D_3 I_3$	19.15	21.3	16.2	15.8	+11	-10	-17

*Calibration treatment

Rijtema) were compared with observed tuber yields. Overall, the simulated tuber yields deviated from actual observations within -28 to +19 % over the two crop seasons. A comparison of measured and simulated tuber yields revealed that these were predicted within -13 to +9 % in the autumn crop season and within -28 to +11 % in the spring crop season (Table 3).

Priestly-Taylor equation gave a better estimate of tuber yields than other equations in the autumn season which may be due to its better performance under non-advective moisture conditions, however, Penman equation gave a relatively better estimate in the advective moisture conditions of spring crop season.

CONCLUSIONS

The study revealed that the SWACROP model under-estimated as well as over-estimated soil water content and followed actual field observed time-trends. Thus the model is performing satisfactorily and could be used to estimate soil water balance under agroclimatic conditions of Punjab. The results suggested that tuber production subroutine of the model needs further scrutiny with respect to partitioning of photosynthates to various plant parts to simulate growth and yields more realistically.

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