PERFORMANCE EVALUATION OF AQUACROP IN SIMULATING POTATO YIELD UNDER VARYING WATER AVAILABILITY CONDITIONS

Neelam Patel, **P. Kumar and **Neetu Singh
*Senior Scientist and **Research Associates
Water Technology Centre,
Indian Agricultural Research Institute, New Delhi –110012, India
Corresponding author. Tel.: 91-11-25848703; Fax: 91-11-25848703
Email address: neelam@iari.res.in (Neelam Patel))

INTRODUCTION

Potato is one of the most important crops known to civilization. In terms of global production, potato (*Solanum tuberosum L.*) is the fourth most important food crop after maize, rice and wheat. The current production of 306 million tonne represents a modest increase worldwide of 15.5% since the early 1960s. Such global statistics, however, mask the much greater expansion of potato production that has taken place in developing countries versus developed countries during the past 40 years. Much of the increase in potato production in developing countries has occurred in Asia, most notably in China and India. Although yields have improved in both countries, the increase in production can be attributed mainly to a continuous expansion of area planted to potato (FAOSTAT, October 2001). Potato has emerged as an important food crop on the Indo-Gangetic plains on India following an expansion in irrigation infrastructure and the construction of large cold-storage facilities for storing potato before sale and as a seed crop during summer (Bardhan Roy et al., 1999). Whereas potato is grown as a cool, dry-season (winter) irrigated crop on the Indo-Gangetic plains, in China it is grown mostly under rain-fed conditions during summer. The average yield of 15.9 t/ha currently estimated at the global level is much below the yields of 30–50 t/ha commonly obtained across a range of environments and management systems, so it would seem that there is considerable scope for improvement (Allen and Scott, 1992). Critical to achieving improved yields will be access to an adequate water supply, including more efficient use of all available water in both irrigated and rain-fed systems.

The strong demand is putting tremendous pressure on production, hence, competition for available water. At the same time, it increases the price of potato, which in turn has raised food prices in general. Improving the water use efficiency for potato production is therefore of paramount importance to obtain “more crop per drop” with declining worldwide irrigation resources and the uncertainty in temporal and spatial distribution of precipitation. Determining the appropriate drip system requires consideration of soil properties and the crop's root development pattern. Knowledge of soil water distribution in the root zone is therefore essential for the design and management of drip system. The knowledge can be obtained either by conducting field experiments or through modelling.The spatial variations of soil over the Indian region which is affected by the monsoon and show strong variability over different geological terrains. Potato is grown in various soil types and climatic conditions and variable amount of irrigation water in India.

National Committee on the Use of Plasticulture in Horticulture (NCPAH) was constituted by Ministry of Agriculture for the promotion of micro irrigation in India. The committee established 22 Precision Farming Development Centres (PFDC) in different agro climatic zones of India for conducting research on micro irrigation through farmers participation and to submit guidelines to the NCPAH, Ministry of Agriculture to take beneficial technologies to the farmers. Micro irrigation system came to India in seventies but its adoption started only in late eighties. Government started making efforts to promote micro irrigation through part financial support to offset its high initial cost syndrome. Micro irrigation is becoming very popular in potato crop in different parts of India. Farmers are finding difficulty in deciding the amount of irrigation water and its impact on productivity. Therefore AquaCrop model of FAO was tested to develop the water management strategies for growing potatoes without conducting field experimentation in the area of deficit water supply through micro irrigation.

AQUACROP MODEL

Estimating attainable yield under water-limiting conditions will remain central in arid, semi-arid and drought-prone environments. To address this need, FAO has developed a yield-response to water model, AquaCrop, a crop water productivity simulation model resulting from the revision of the FAO Irrigation and Drainage Paper No. 33 “Yield Response to Water” (Doorenbos and Kassam, 1979). For over two decades, this paper has been a key reference for estimating the yield response of field, vegetable and tree crops to water. Similarly to many other crop-growth models, AquaCrop further develops a structure (sub-model components) that includes: the soil, with its water balance; the crop, with its development, growth and yield; the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration (CO_2); and the management, with its major agronomic practice such as irrigation and fertilization. Simulation runs of AquaCrop are executed with daily time steps, using either calendar days or growing degree days. Several features distinguish AquaCrop from other crop growth models achieving a new level of simplicity, robustness and accuracy.

FIELD DATA COLLECTION

Potato crop was planted at the PFDC, IARI, New Delhi, India during the years 2008-09 and 2009-10. The study area lies at 28.08^0N latitude and 77.12^0E longitude. The height above mean sea level is 229m. The experiment consisted of 12 Treatments on depth and frequency of irrigation. Drip irrigation was scheduled to replenish the water lost through ET. The observations on biomass and yield were carried out at major crop growth stages for both the years. The crop parameters observed during 2008-09 were used for local crop calibration. Using these crop parameters, growth and yield of potato crop was simulated by AquaCrop model for the year 2009-10. Treatments taken in potato crop are given in Table 1. The following are the main features of the experiment relevant to the simulation tests:

Year	**2008-09**	**2009-10**
Date of sowing	17-20 October, 2008	21-24 October, 2009
Crop & variety	Potato, Kufri Badshah	Potato, Kufri Badshah

Spacing	row to row and plant to plant spacings were 60 cm and 30 cm	row to row and plant to plant spacings were 60 cm and 30 cm
Irrigation system	Subsurface drip tape system with dripper at 30 cm apart having discharge 1.5 LPH at 1 kgf/cm^2	Subsurface drip tape system with dripper at 30 cm apart having discharge 1.4 LPH at 1 kgf/cm^2
Date of harvesting	14-17 February, 2009	23-26 February, 2010
Soil type	Sandy loam	Sandy loam

Table 1: Treatments on depth and frequency of irrigation

Treatments	Irrigation depth (% of irrigation water requirement)	Irrigation frequency
VD100	100	Daily
VA100	100	Alternate day
VB100	100	Biweekly
VW100	100	Weekly
VD80	80	Daily
VA80	80	Alternate day
VB80	80	Biweekly
VW80	80	Weekly
VD60	60	Daily
VA60	60	Alternate day
VB60	60	Biweekly
VW60	60	Weekly

MODEL CALIBRATION FOR POTATO CROP

In AquaCrop, the crop system has five major components and associated dynamic responses: phenology, aerial canopy, rooting depth, biomass production and harvestable yield. The crop grows and develops over its cycle by expanding its canopy and deepening its rooting system while at the same time the main developmental stages are established. Local calibration for potato crop was done using the observations made during the year 2008-09. Out of all the crop parameters in AquaCrop, 23 of them were demonstrated or assumed to be conservative (constant) in the study of Hsiao et al. (2009). The same values of this set of 23 parameters were used to evaluate the performance of AquaCrop. These parameters are presumed to be applicable to a wide range of conditions and not specific for a given crop cultivar or management practices. For convenience, all other crop parameters (site-, management-, and cultivar-specific parameters) such as soil water characteristics, maximum rooting depth, plant density, sowing date, and phenology have been considered under the heading of user-specific input parameters.

SIMULATION OF POTATO GROWTH AND YIELD FOR THE YEAR 2009-10

Climate Parameters

The atmospheric environment of the crop is described in the climate component of AquaCrop and deals with key input meteorological variables. Five weather input variables are required to run AquaCrop: daily maximum and minimum air temperatures, daily rainfall, daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo), and the mean annual carbon dioxide concentration in the bulk atmosphere. While the first four are derived from typical agrometeorological stations, the CO_2 concentration uses the Mauna Loa Observatory records in Hawaii. The climatic parameters observed at PFDC field are given in Figure 1.

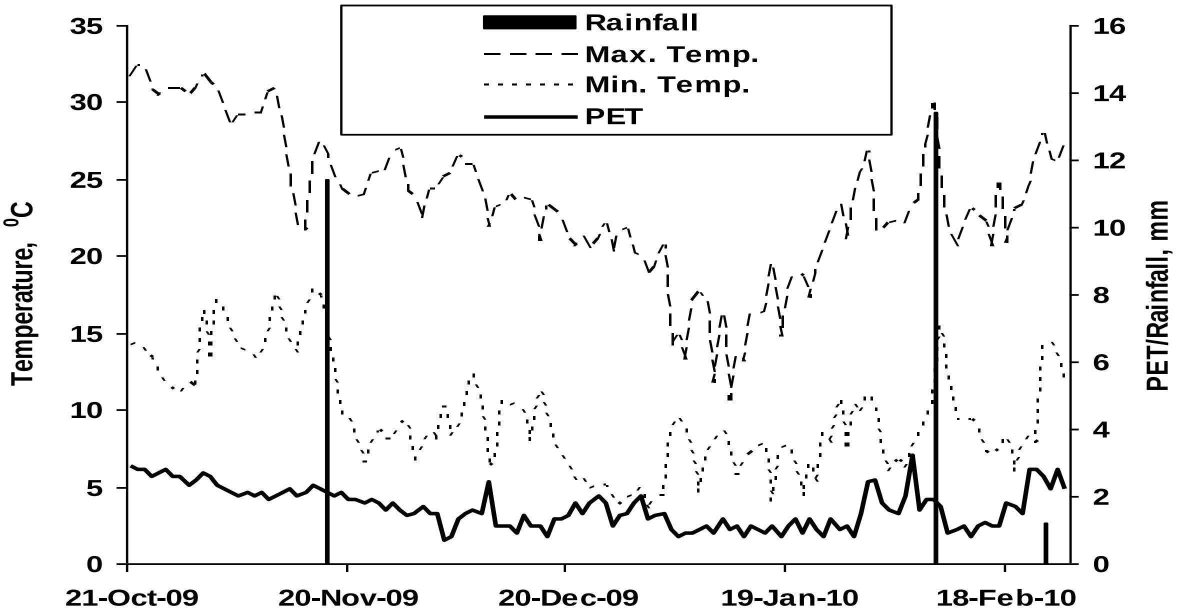

Figure 1: Climatic parameters at IARI during 2009-10

Water Management Parameters

The AquaCrop considers water management options related to (i) rainfed-agriculture (no irrigation), and (ii) irrigation where, after selecting the method (sprinkler, drip, or surface, either by furrow or flood irrigation), the user can define its own schedule on the basis of depth or timing criteria, or let the model to automatically generate the scheduling on the basis of fixed interval, fixed depth, or fixed percentage of soil water content criteria. The irrigation option is particularly suited for simulating the crop response under supplemental or deficit irrigation. The daily water requirement for potato crop during growing season of 2009-10 is given in Figure 2

PERFORANCE EVALUTION OF AQUACROP

For the performance evaluation of AquaCrop, following notations were used:

Si = simulated value
Oi = observed value,
N = number of observations

$\overline{O_i}$ = mean value of Oi

$\overline{S_i}$ = mean value of S_i

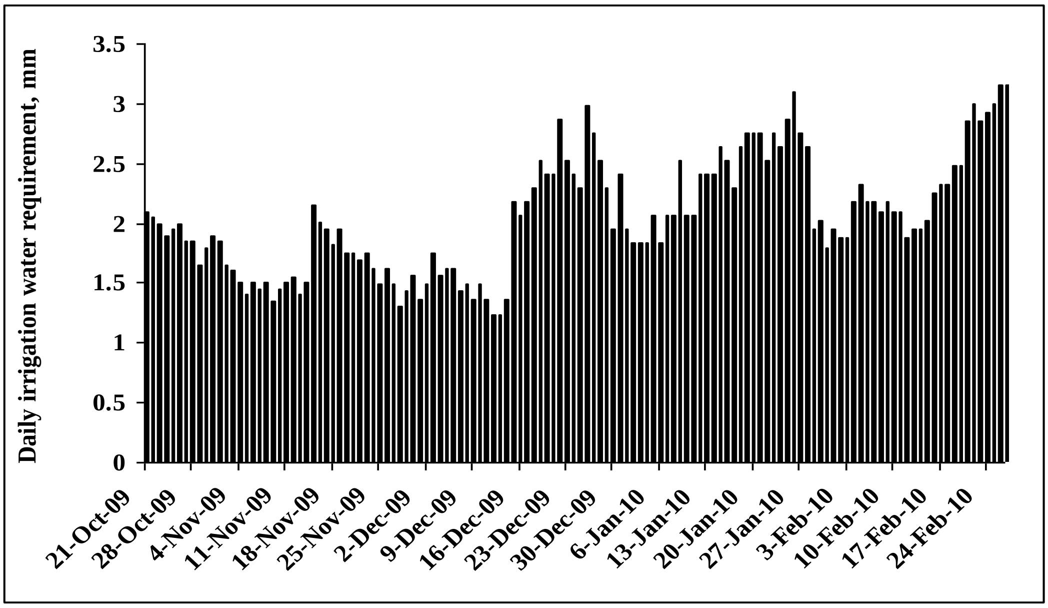

Figure 2: Daily irrigation water requirement for potato crop during 2009-10

Average Absolute Error (AAE)

Absolute percentage error between simulated and observed values may be calculated using Equation 1.

$$AAE = \frac{\sum_{i=1}^{N} |O_i - S_i|}{N} \quad (1)$$

Root Mean Square Error (RMSE)

Root mean square error (RMSE) is calculated as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (O_i - S_i)^2}{N}} \quad (2)$$

The RMSE represents a measure of the overall, or mean, deviation between observed and simulated values, that is, a synthetic indicator of the absolute model uncertainty. In fact, it takes the same units of the variable being simulated, and therefore the closer the value is to zero, the better the model simulation performance.

Coefficient of Efficiency (E)

Coefficient of efficiency, E (Nash and Sutcliffe, 1970) is calculated using Equation 3.

$$E = 1 - \frac{\sum_{i=1}^{N}(O_i - S_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O_i})^2} \tag{3}$$

The coefficient of efficiency (E) expresses how much the overall deviation between observed and simulated values departs from the overall deviation between observed values ($\overline{O_i}$) and their mean value ($\overline{O_i}$). The added value of this statistical indicator (E) as compared to RMSE, is in its ability to capture how well the model performs over the whole simulation span, for example, along the season. In other words, while RMSE does not distinguish between large deviations occurring in some part of the season and small deviations in other part of the season, E accounts for the different deviations, as they depart from ($O_i - \overline{O_i}$) along the season and expresses an efficiency of the model performance, that is, the smaller the departure from ($O_i - \overline{O_i}$), the higher the performing efficiency of the model. The E is unitless and may assume values ranging from $-\infty$ to +1, with better model simulation efficiency when values are closer to +1.

Correlation coefficient

The correlation coefficient is an indicator of degree of closeness between observed values and model estimated values. The observed and simulated values are found to be better correlated as the correlation coefficient approaches to 1. If observed and predicted values are completely independent i.e., they are uncorrelated then CC will be zero (Mutreja, 1992). The correlation coefficient was estimated by the Equation 4.

$$CC = \frac{\sum_{i=1}^{N}\left[(O_i - \overline{O_i})(S_i - \overline{S_i})\right]}{\sqrt{\sum_{i=1}^{N}(O_i - \overline{O_i})^2 \sum_{i=1}^{N}(S_i - \overline{S_i})^2}} \tag{4}$$

Performance of AquaCrop in Simulating Dry Matter Yield of Potato

The simulated and observed dry matter yields after major crop growth stages of potato during 2009-10 are shown in Figures 3 to 5 and the statistical parameters are given in Table 2. The table suggests that the maximum yield simulated by AquaCrop was underestimated whereas minimum yield was slightly overestimated. Minimum simulated and actual yields were for the VW treatment. This is justified as VW60 treatment is getting least quantity of water and maximum water stress. AquaCrop simulated maximum yield for VD100 treatment whereas field data showed maximum yield for VA100 treatment.

The good agreement between measured and simulated is also reflected in the statistical analysis, with low average absolute error and RMSE. The corresponding yields for different treatments were also well simulated with the observed yields giving coefficient of efficiency 0.435 to 0.63. The simulated yields are very close to the actual yields for full irrigated and mild stress treatments. In case of high water stress treatments (VB60 and VW60), error between simulated and observed values became more significant. The discrepancy between measured and simulated results in the drier treatments could also be due to the variable soil depth as reported in Cavero et al. (2000). The spatial variability of the soil could cause some differences in measured values especially in the water stress treatments. (Hsiao et al., 2009).

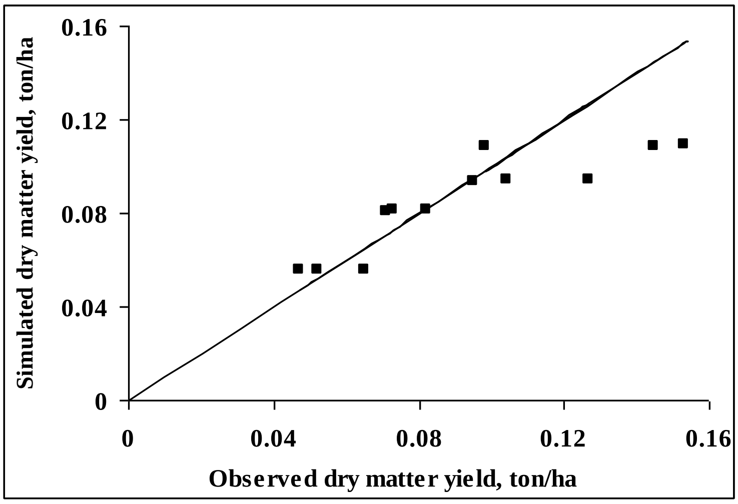

Figure 3: Simulated and observed dry matter yields after development stage during 2009-10

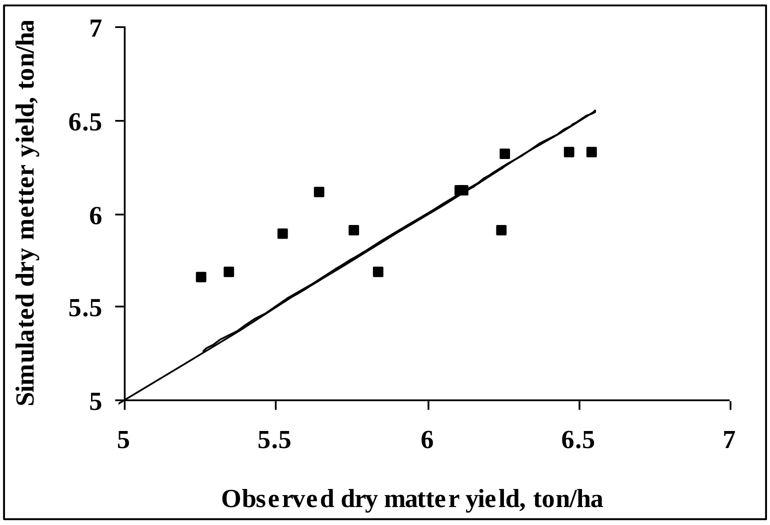

Figure 4: Simulated and observed dry matter yields after middle stage during 2009-10

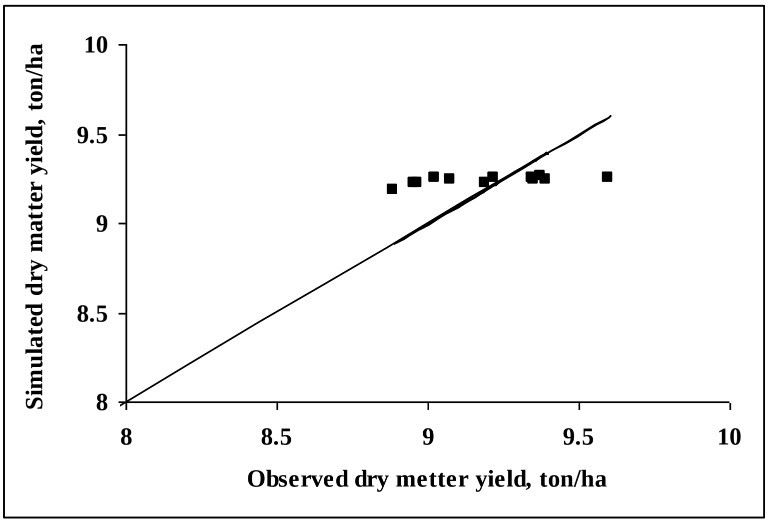

Figure 5: Simulated and observed dry matter yields after end stage during 2009-10

Table 2: Statistical parameters obtained from simulated and observed dry matter yield of potato after major growth stages during 2009-10

Treatments	Development Stage		Middle Stage		End Stage	
	Simulated	Actual	Simulated	Actual	Simulated	Actual
VD100	0.109	0.153	6.321	6.548	9.263	9.376
VD80	0.109	0.145	6.317	6.472	9.257	9.216
VD60	0.109	0.098	6.312	6.263	9.252	9.021
VA100	0.094	0.127	6.114	6.109	9.251	9.597
VA80	0.094	0.104	6.114	6.124	9.251	9.346
VA60	0.094	0.095	6.103	5.647	9.238	9.352
VB100	0.081	0.082	5.902	6.249	9.241	9.393
VB80	0.081	0.073	5.902	5.763	9.241	9.076
VB60	0.081	0.071	5.883	5.526	9.219	8.952
VW100	0.056	0.065	5.683	5.842	9.227	9.188
VW80	0.056	0.052	5.678	5.352	9.222	8.966
VW60	0.056	0.047	5.647	5.257	9.189	8.886
Average Absolute Error	**0.015**		**0.218**		**0.177**	
Root Mean Square Error	**0.02**		**0.264**		**0.202**	
Coefficient of Efficiency	**0.63**		**0.586**		**0.435**	
Correlation Coefficient	**0.877**		**0.816**		**0.67**	

Performance of AquaCrop in Simulating Above-ground Dry Biomass

The simulated and observed above-ground dry biomass after major crop growth stages of potato during 2009-10 are shown in Figures 6 to 9 and the statistical parameters are given in Table 7. The table shows that the simulated values of above-ground dry biomass are in good agreement with the observed values after initial and end stages with low average absolute error and RMSE. For these two stages, corresponding values for different treatments were also well simulated with the observed yields giving correlation coefficient of 0.743 and 0.723. For other two stages, the simulated values are not well correlated as the coefficient of efficiency and the correlation coefficient is low.

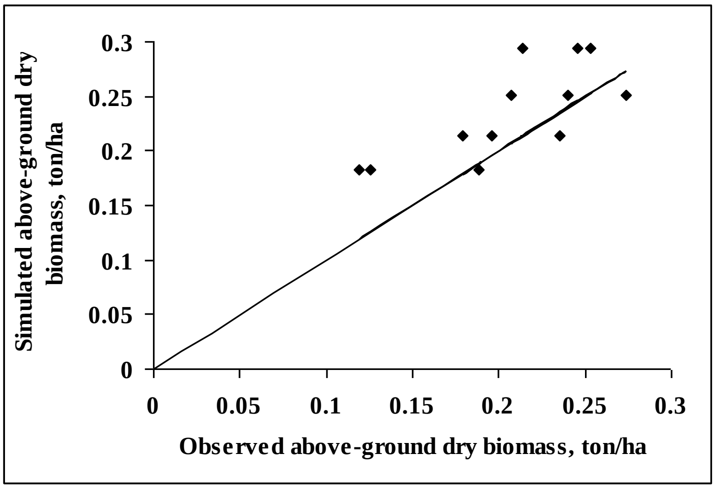

Figure 6: Simulated and observed above-ground dry biomass after initial stage during 2009-10

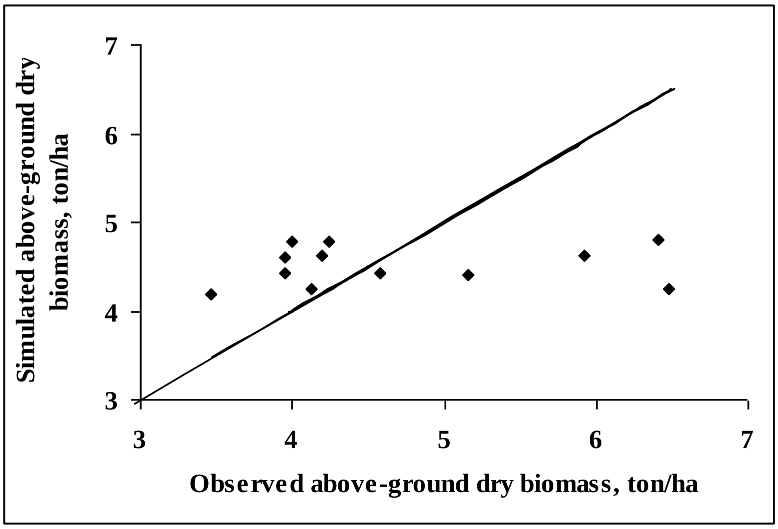

Figure 7: Simulated and observed above-ground dry biomass after development stage of potato crop during 2009-10

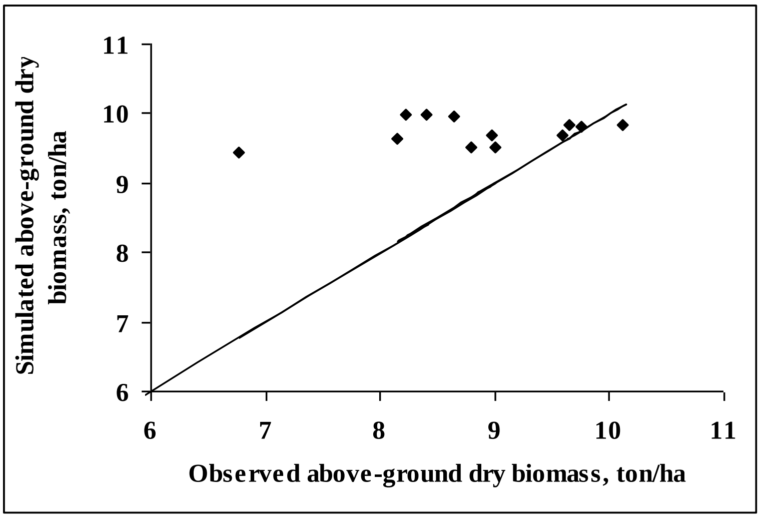

Figure 8: Simulated and observed above-ground dry biomass after middle stage of potato crop during 2009-10

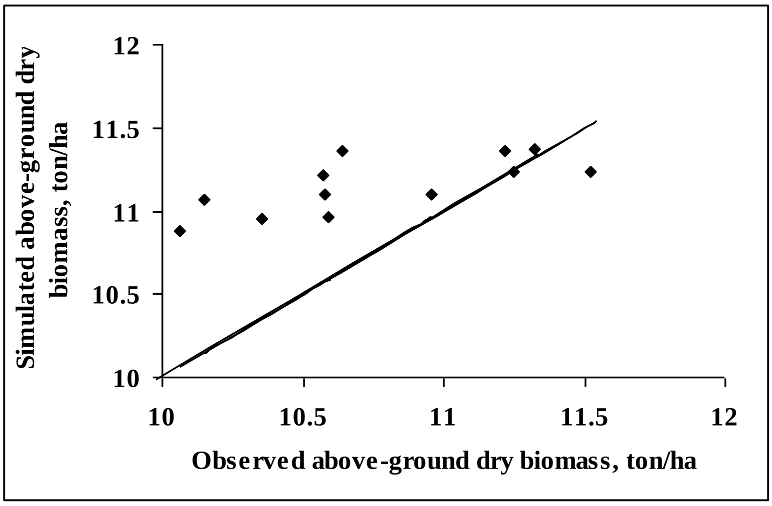

Figure 9: Simulated and observed above-ground dry biomass after end stage of potato crop during 2009-10

Table 3: Statistical parameters obtained from simulated and observed above-ground dry biomass of potato after major growth stages during 2009-10

	Initial Stage		Development Stage		Middle Stage		End Stage	
Treatment	**Simulated**	**Actual**	**Simulated**	**Actual**	**Simulated**	**Actual**	**Simulated**	**Actual**
VD100	0.294	0.253	4.796	6.411	9.987	8.400	11.374	11.326
VD80	0.294	0.246	4.788	4.001	9.980	8.216	11.366	11.217
VD60	0.294	0.214	4.780	4.244	9.972	8.639	11.358	10.639
VA100	0.251	0.274	4.614	4.189	9.835	10.120	11.239	11.520
VA80	0.251	0.240	4.614	5.917	9.835	9.646	11.239	11.246
VA60	0.251	0.207	4.595	3.950	9.815	9.752	11.219	10.572
VB100	0.214	0.235	4.432	3.950	9.683	9.593	11.103	10.959
VB80	0.214	0.196	4.432	4.578	9.683	8.976	11.103	10.576
VB60	0.214	0.179	4.400	5.156	9.646	8.150	11.067	10.150
VW100	0.182	0.189	4.247	6.478	9.525	8.788	10.961	10.588
VW80	0.182	0.126	4.238	4.128	9.516	9.000	10.952	10.354
VW60	0.182	0.119	4.189	3.467	9.445	6.765	10.881	10.065
AAE	0.037		0.813		0.954		0.436	
RMSE	0.043		1.006		1.234		0.528	
E	0.133		0.036		0.098		0.329	
R	0.743		0.113		0.297		0.723	

CONCLUSIONS

AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water of most of the major field and vegetable crops cultivated worldwide. One important application of AquaCrop would be to compare the attainable against actual yields in a field, farm, or a region, to identify the constraints limiting crop production and water productivity (benchmarking tool). It can also be very useful for scenario simulations and for planning purposes for use by economists, water administrators and managers. It is suited for perspective studies such as those under future climate change scenarios. Overall, it is particularly suited to develop agricultural water management strategies for a variety of objectives and applications. Its performance has been tested for several crops with very satisfactory results.

The particular features that distinguishes AquaCrop from other crop models is its focus on water, the use of ground canopy cover instead of leaf area index, and the use of water productivity values normalized for atmospheric evaporative demand and of carbon dioxide concentration that confer the model an extended extrapolation capacity to diverse locations and seasons, including future climate scenarios. Moreover, although the model is simple, it gives particular attention to the fundamental processes involved in crop productivity and in the responses to water, from a physiological and agronomic background perspective. Good agreement was obtained by AquaCrop in simulating the yields under full and deficit irrigation. The model was less satisfactory in simulating yields under high water stress conditions. Also, the model was found to be less satisfactory in predicting above-ground dry biomass.

While some difficulties were encountered by AquaCrop in simulating high water stress treatments, it could be the fault of the model, or it could also be errors in measurement. For water-deficient conditions, soil water characteristics are of critical importance, but it is not uncommon for field capacity and permanent wilting percentage to be estimated by different procedures with somewhat different outcome. Nevertheless, even with the rather extensive simplification as discussed in Steduto et al. (2009) and Hsiao et al. (2009), the model has been shown to be robust in the simulation of the potato yield and biomass.

Although, the effect of severe water stress needs further assessment and probably development, the ability of AquaCrop to simulate mild water stress occurring at various stages in the growing period makes it very useful for the design and evaluation of deficit irrigation strategies, water management options, and to study the effect of location, soil type, irrigation management, and sowing date on plant production under rainfed and irrigated agriculture. The simplicity of AquaCrop in its required minimum input data, which are readily available or can easily be collected, makes it user-friendly.

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