CROP WATER USE AND POTENTIAL PRODUCTION UNDER CONTRASTING WATER REGIMES

Nuril Hidayati

Puslitbang Biologi-LIPI, Bogor

ABSTRACT

Crop water use, efficiency of water use and potential production of Vicia faba *crop were studied using a dynamic model. The model consists of two main models. i.e. Crop growth and water balance models which were linked by index of growth reduction due to water stress. The results from the simulation was validated using data provided from two years field experiments in 1989 and 1990. The model simulated crop water use, water use efficiency and crop production reasonably well for both years. The biggest differences between simulation and observation on crop water use were 22.1 % for irrigation treatment in 1989 and dry treatment in 1990. In relation to crop production under different water treatments, the model tend to underestimate final harvest of dry matter productions under water limited conditions. Inspite of the underestimation above, the model simulated crop production under irrigated and rainfed conditions quite closely for both years.*

Key word : crop water efficiency, Vicia faba, dynamic model simulation, irrigated land, rainfed land.

ABSTRAK

Penggunaan air, efisiensi air dan potensi produksi pada pertanaman *Vicia faba* telah diteliti menggunakan model dinamis. Model tersebut terdiri atas dua model utama yaitu : model pertumbuhan tanaman dan model neraca air yang keduanya berkaitan dengan indeks pengurangan pertumbuhan akibat cekaman air. Hasil simulasi kemudian divalidasi menggunakan data percobaan lapang pada musim tanam tahun 1989 dan 1990. Hasil analisi menunjukkan bahwa model yang digunakan dapat menggambarkan dengan baik hubungan antara penggunaan air, efisiensi air dan produksi pertanaman. Perbedaan terbesar antara model simulasi dengan hasil pengamatan untuk penggunaan air oleh tanaman adalah 22.1% baik untuk perlakuan pemberian air pada tahun 1989 maupun untuk perlakuan pengeringan pada tahun 1990. Dalam hubungan dengan produksi, model yang digunakan cenderung menduga produksi bahan kering lebih rendah pada keadaan air terbatas. Di luar keadaan tersebut model dapat digunakan secara baik untuk pendugaan produksi pada daerah beririgasi maupun tadah hujan untuk dua tahun percobaan di atas.

Kata kunci : efisiensi air pertanaman, *Vicia faba*, simulasi model dinamis, lahan beririgasi, lahan tadah hujan.

INTRODUCTION

Performance of a crop is determined by interaction between its genetic potential and environment. Major environmental factors which determine crop productivity are irradiance, air temperature, precipitation and soils. Among these environmental factors that influence the expression of genetic potential of a crop and determine its productivity, availability of water is one of the most crucial (Grashoff, 1990; de Costa, 1992). In fact, availability of water also determine the timing of growing season (Bunting, 1975).

Differences in pattern and variation in the amount of water supply are also important causes of yield instability (Grashoff, 1990). As drought is caused by complex interaction of environmental factors, it is difficult to understand it with single field experiment. Therefore, extensive studies are required to investigate the interactions.

In this research, a simulation model and field experiments were used to study the effects of management of water application on water use and productivity of *Vicia faba* crop.

Some static photosynthesis models have been used to estimate dry matter production of faba bean (Ratnaweera, 1991; de Costa, 1992; del Pozo, 1992). However, these static models are not sufficient to study integrated factors affecting crop growth and production. By using an alternative of dynamic simulation model it is possible to introduce some major and more complex environmental factors which influence crop production. In order to achieve the proposed objectives, a preliminary dynamic simulation model which could be classified as being mathematical, mechanistic and continuous was constructed to be used as a research tool. The results were then compared with observation from field experiments at the same environmental conditions.

METHODS

The model consists of crop growth and water balance models. The growth model consists of photosynthesis, maintenance respiration, growth process, developmental stages, leaf area development and partitioning models. The water balance model considered rain and irrigation as sources of soil water, transpiration, evaporation and drainage as water depletion from the soil. Both main models were linked by the degree of growth reduction as a function of soil water deficits. Application of water treatments in the model was calculated by adding water (for irrigation treatment) and reducing water (for dry treatments) to rainfall input data which was counted as daily input data. The amount of water applied and the interval of irrigation is presented in Table 1.

The model followed the rule of CSMP (Continuous Simulation Modelling Program) for Personal Computer (PC).

Experimental data used to test the model were provided from field experiments conducted by de Costa (1992) in the growing seasons of 1989 and 1990.

Sowing and Crop Establishment

This study used a determinate type of faba bean, cultivar TINA. In the first season the crops were sown on 18 April 1989 with the rate of 80 plants m^{-2}. Seedling emerged around 20 days after planting (20 DAS). In second season experiment, the crops were sown on 30 March 1990. The final plant densities ranged 48 - 68 plants m^{-2}.

Application of Water Treatments

It was decided to simulate water use and dry matter production of faba bean under different conditions of soil water. Therefore, in this experiment, four water treatments were applied.

W1 : the crops were grown under irrigation throughout the growing period.
W2 : the crops were covered and irrigated once, just after flowering.
W3 : the crops were grown under dry condition, without supplementary water neither from irrigation nor rainfall.
W4 : rainfed treatment.

Table 1. Water treatments (W1) in the growing seasons of 1989 and 1990

1989		1990	
Time	Water (mm)	Time	Water (mm)
7 June	47	8 May	95
15 June	47	18 May	81
21 June	62	24 May	101
30 June	43	1 June	102
12 July	74	15 June	87
18 July	81	2 July	116
25 July	90	9 July	95
1 August	71	16 July	95
-	-	21 July	98
-	-	27 July	97
-	-	2 August	97

RESULTS

Seasonal Variation of Crop Water Use Under Different Water Regimes

In general, the model simulates total water use under all of water treatments (W1, W2, W3 and W4) reasonably well, except for some underestimate , particularly in 1990 at early stage, up to 50 DAS. Figure 1 shows how the amount of water is transpirated by crop canopy varied with soil moisture levels. Under irrigation, where soil moisture deficit did not occur, the crop absorbed sufficient water, resulting in a high level of transpiration, which reaching maxima of 364 mm in 1989 and 349 mm in 1990 (Table 2). These values agree with the observation, where total amount of water transpirated were 304 mm in 1989 and 374 mm in 1990. However, under water shortage condition, the model tend to slightly underestimate crop water use at early stage, especially in the season of 1989.

This underestimation of total crop water use at early stage apparently related with the underestimation of dry matter production before day 47 in 1989 and day 53 in 1990 (Figure 2).

Crop Productions

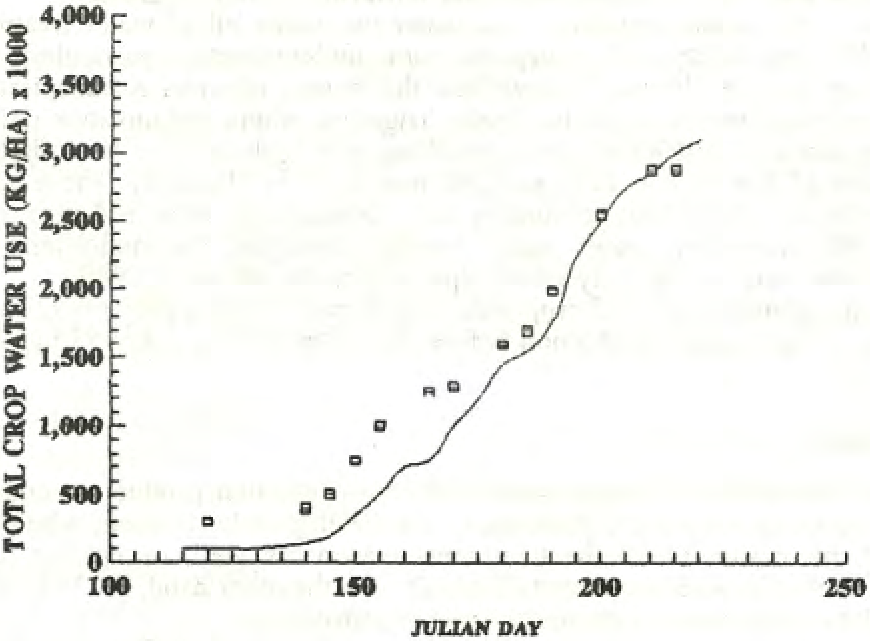
Figure 2 shows that the model simulated total dry matter production under different water treatments reasonably well, particularly for 1990 growing season, where the model predicted total dry matter of all the treatments reasonably well, except for that at final harvest which tend to be underestimated (Table 2). On the other hand, for W2, W3 and W4, the model slightly overestimated the linear stage of growth.

Under water deficit, simulated total dry matter decreased with increasing soil water deficits. The crop grown under irrigation (W1) produced the highest dry matter yield, whereas dry condition (W3) produced the lowest dry matter. The crops grown under rainfed condition (W4) were able to produce higher dry matter than W3 by using available water from the rain during the season. This variation in dry matter yield were closely correlated with soil water conditions and amount of water used by the crop which are sown in Figure 1.

Table 2. Predicted (SIM) and observed (REAL) of total actual evapotranspiration (AEVAP), maximum production of dry matter (WSH) and economic yield (WSO) under different water treatments of 1989 and 1990 seasons.

Treatment	WSH (kg ha^{-1})			WSO (kg ha^{-1})			AEVAP (mm)		
	SIM	%	Observed	SIM	%	Observed	SIM	%	Observed
1989									
W1	4660	7.5	12170	5550	7.4	5140	0-364	16.5	0-304
W2	2590	40.0	7760	1400	67.8	4360	0-188	7.5	0-174
W3	3320	39.0	4240	486	82.9	2850	0-125	32.0	0-85
W4	11250	14.7	3890	1030	30.9	1490	0-150	22.7	0-166
1990									
W1	12120	6.2	11360	6140	24.9	4610	0-39	6.7	0-374
W2	1990	3.9	5200	1460	47.2	2760	0-168	8.7	0-184
W3	2950	25.2	3940	702	60.6	1780	0-118	7.8	0-128
W4	4290	0.1	4290	1480	32.9	2200	0-154	11.5	0-174

Under non-limited water (W1), the model predicted 7.5% lower dry matter than the real production, which was 12.2 t ha^{-1} in 1989. However, in 1990 it predicted 2% higher total dry matter than the observed, which was 11.4 t ha^{-1} (Table 2). Under rainfed condition (W4), the model resulted 14.7% less dry matter in 1989 which was 3.9 t ha^{-1} and only 0.1% different for 1990, which was 4.3 t ha^{-1}. Surprisingly, for W2 and W3 treatments, the model highly underestimated dry matter, especially for 1989 season. Under dry condition (W3) the model underestimated total dry matter for both seasons.



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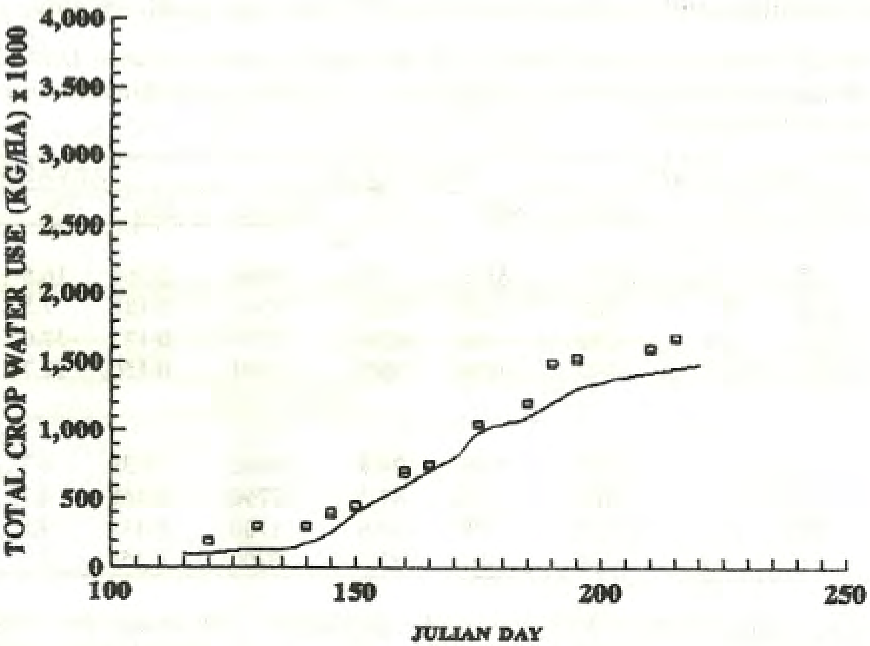

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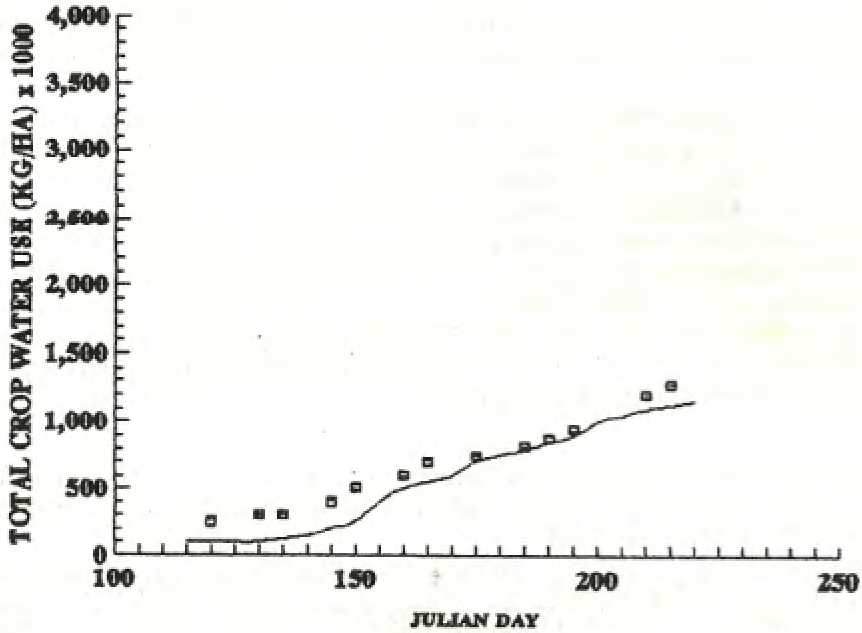
Figure 1a. Total Crop Water Use Under Irrigated (a), Dry and Irrigated Just After Flowering (b), in 1990 Season, Simulated (—) Compared to The Real Data (□).



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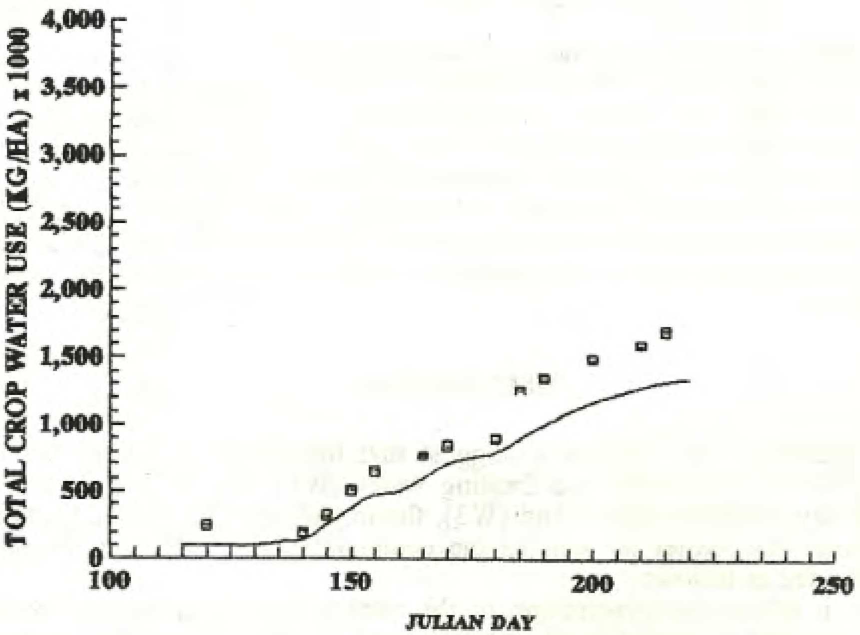

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Figure 1b. Dry (c) and rainfed (d) in 1990 season, simulated (-) compared to the real data (▫).

Relationship Between Crop Production and Crop Water Use

One alternative, and the most commonly used assessment of the effect of water treatments on crop yields is the efficiency of water use which can be defined as the slope of the linear relationship between dry matter production and total water use (Fisher & Turner, 1978).

The linear relationship between crop water use and total dry matter production was simulated by the model. Result of the simulation showed a good agreement with that of the observed (Table 3 & Figure 3). The relationship between total dry matter production and total crop water use was significantly close with the value of R^2 of 0.97 in 1989 and 0.95 in 1990 (Table 3). The efficiency of crop water use were simulated as 3.4 g kg^{-1} in 1989 and 3.9 g kg^{-1} in 1990. Meanwhile, the results of field experiments were 4.19 $\pm$ 0.82 g kg^{-1} in 1989 and 3.15 $\pm$ 0.43 g kg^{-1} in 1990 (Table 3).

This linear relationship was also fitted for the corresponding relationship between total seed yields (WSO) at the end of the season and seasonal total transpiration. The respective parameters values are given in Figure 3.

Table 3. Simulated (SIM) and observed values of crop water use efficiency in term of total dry matter yield (WSH) and seed yield (WSO) to total crop water use (AEVAP) of 1989 and 1990.

Year	WSH/AEVAP		WSO/AEVAP	
	SIM	Observed	SIM	Observed
1989	3.4	4.19 ± 0.82 R^2 =0.95	1.95	2.25 ± 0.59 R^2 =0.91
1990	3.9	3.15 ± 0.43 R^2 = 0.97	1.67	1.56 ± 0.20 R^2 = 0.97

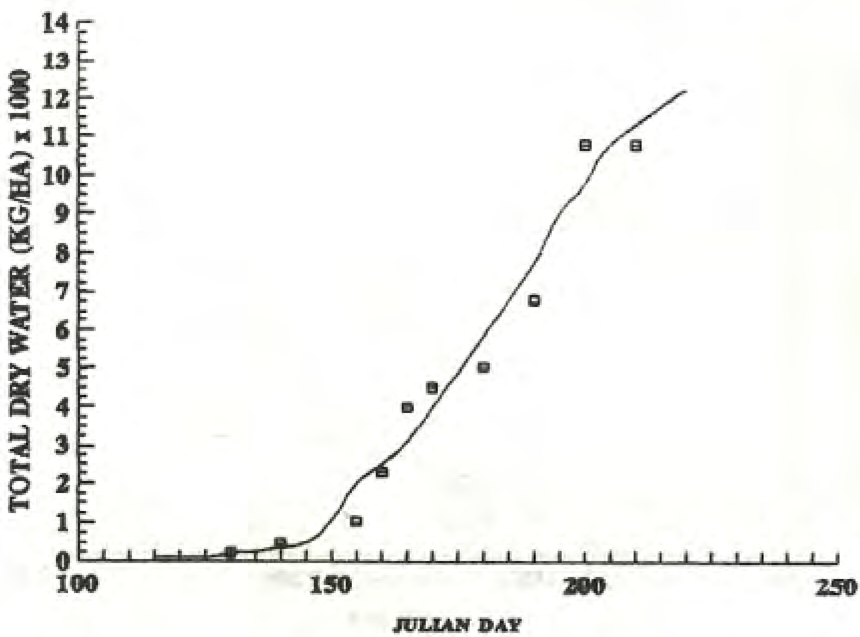
In the model, relationship between crop yields and crop water use was simulated based on calculation proposed by de Wit (1958). If pan evaporation values were constant throughout the life of the crop, water use efficiency would be the ratio of dry matter and pan evaporation. Since evapotranspiration varies within and between seasons so does water use efficiency and it must be investigated by comparing total dry matter yield at the end of the season (WSH and WSO) and the respective seasonal total crop water use (CATRAN). The results of the linear relationship (Figure 3), agrees with the result from field experiment, where the relationship between crop dry matter production and total crop water use was significantly close.

DISCUSSIONS

Overall results of the simulation suggest that the model simulates the faba bean production reasonably well under non-limiting water (W1) and rainfed (W4) conditions. However, under dry conditions (W2) and (W3), the model significantly underestimated the production of total dry matter as well as the economic yield. These phenomena could possibly be explained as follows.

One reason of the underestimation of the storage organ is possibly because of the differences in soil water deficit between simulation and the real data are bigger at the end of the growing period. It resulted in a substantial reduction more to the later period of the crop growth than the earlier one. Consequently, it brought about a substantial reduction on pod growth, since it occurs at the later stage.

Water stress indices was calculated based on soil water deficit within 1 m depth. This may underestimate the real soil water deficits which is usually larger in the upper rooting zone (about 0.7 - 0.85 m) (Husain *et al.*, 1990). From this basis of the rooting zone, Husain *et al.* (1990) reported that the threshold potential soil water deficit at which stress begin was about 65 mm for faba bean, and yield declined linearly with increase in water deficits above this value.



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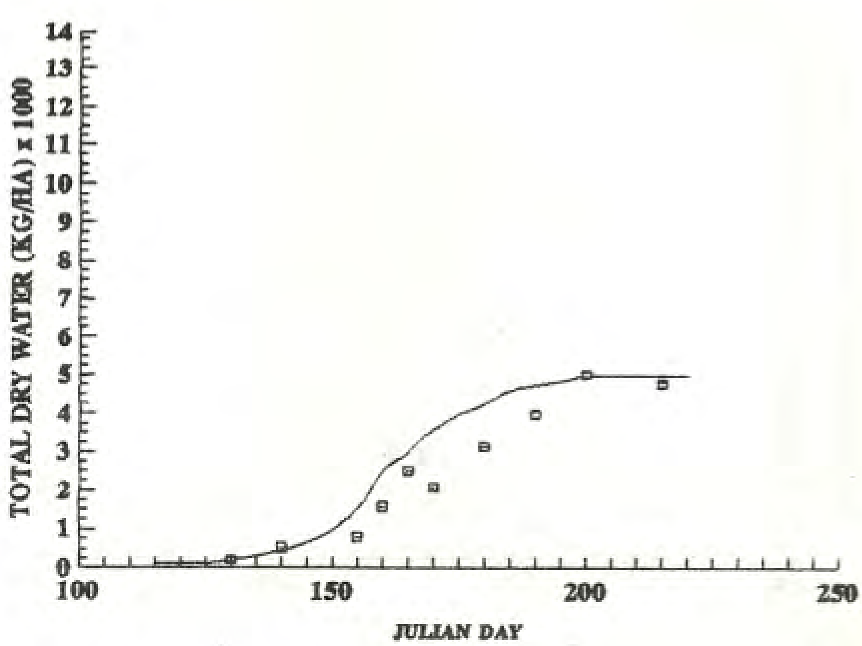
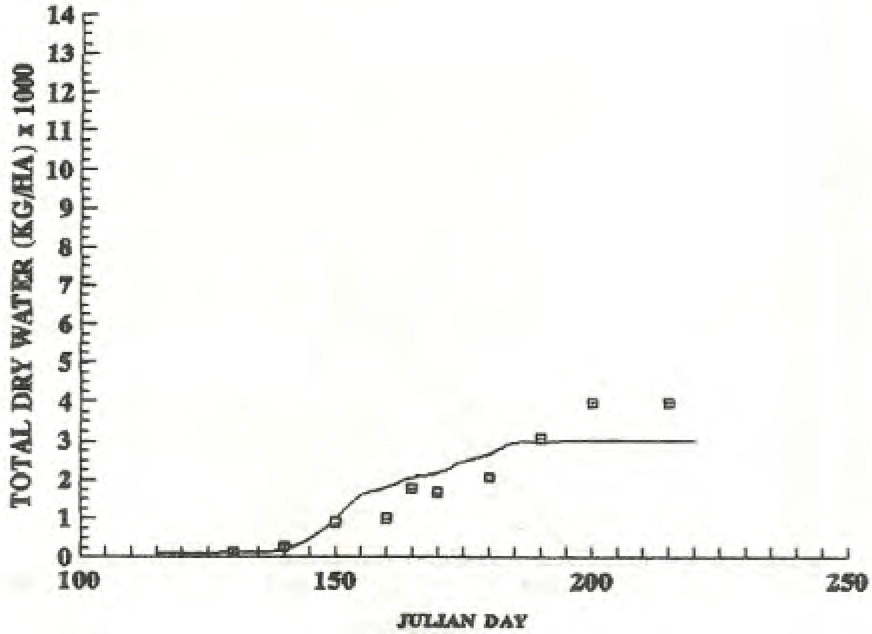


(b)

Figure 2a. Total dry matter production under irrigated (a), dry and irrigated just after flowering (b), in 1990 season, simulated (—) compared to the real data (▫).



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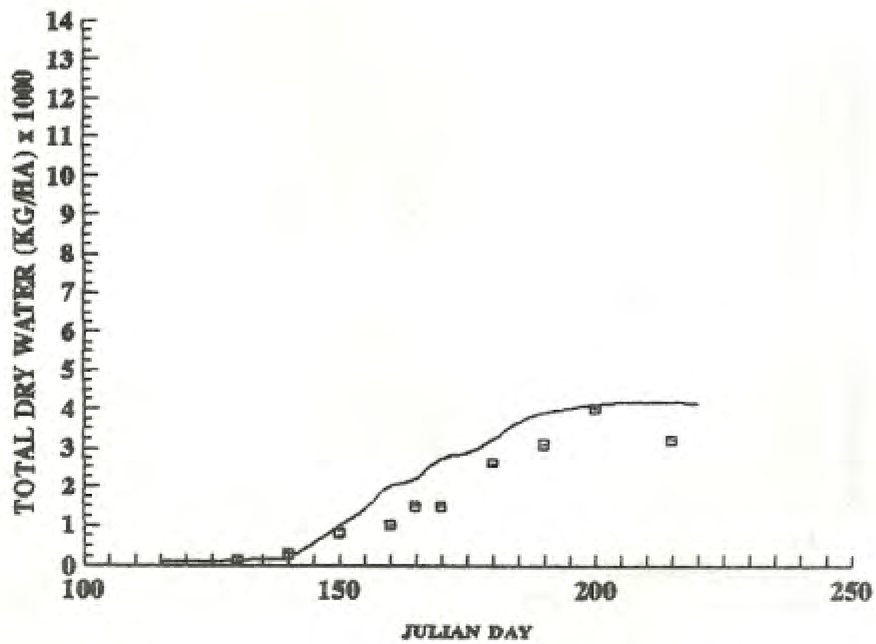

(d)

Figure 2b. Dry (c) and rainfed (d) in 1990 season, simulated (-) compared to the real data (▫).

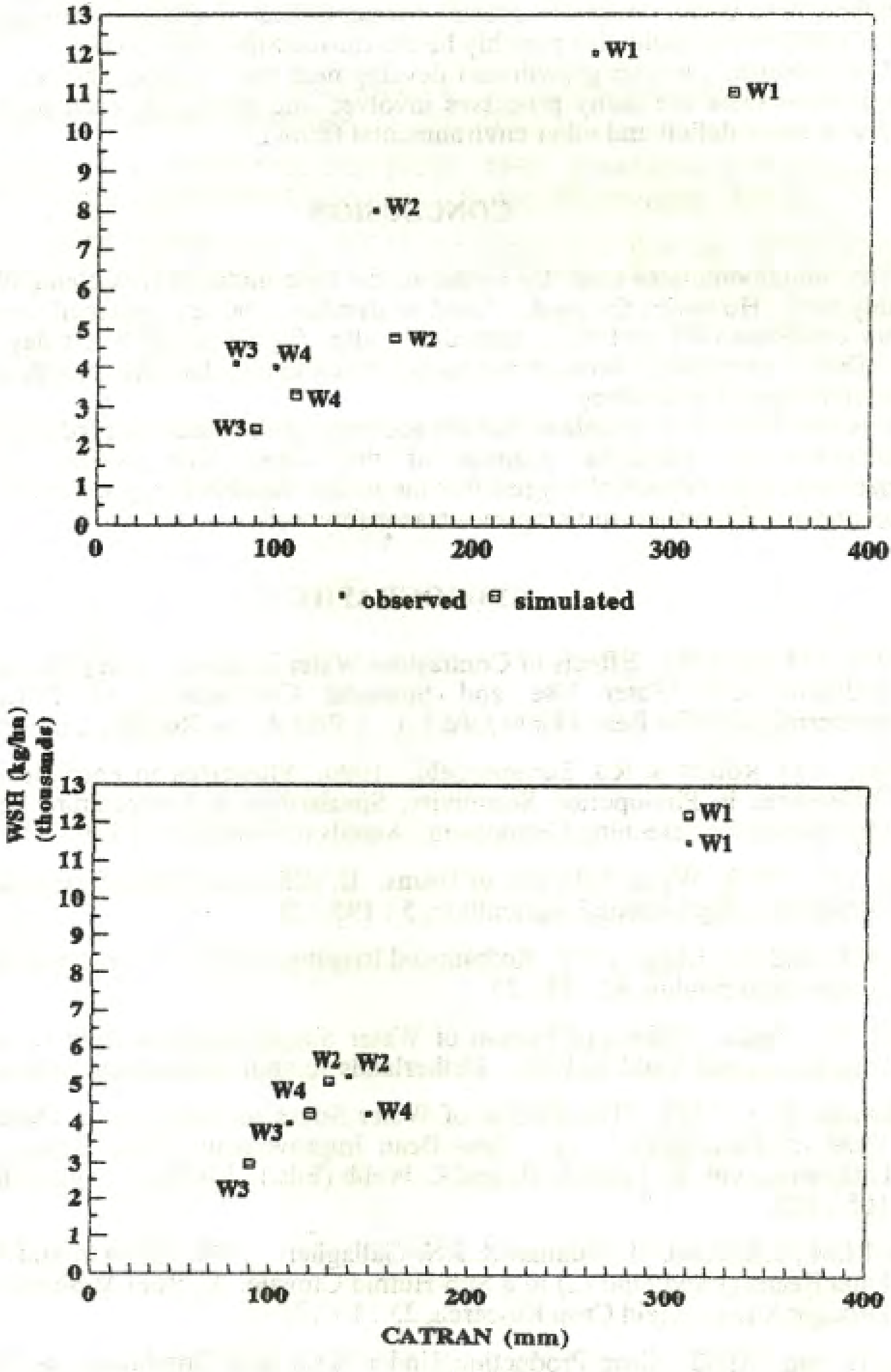

Figure 3. Relationship between total above-ground dry matter (WSH) and total crop water use (CATRAN) under different water treatments in 1989 (Above) and 1990 (Below). simulated (▫) Fitted to The Real Data (•).

Other possible reason for the differences between the results from the simulation and the observation is the partitioning. Due to limited information on partitioning of the cultivar used here, published values for general determinate cultivar was used. The fact that the model did not take into account the effects of water deficit on the developmental stages and process of partitioning could also possibly be the cause of the differences.

The reduction on crop growth and development due to water shortage is not easily explained, since there are many processes involved and moreover, each process response differently to water deficit and other environmental factors.

CONCLUSION

The model simulates total dry matter of the crop under W1, W2 and W4 treatments reasonably well. However, the model failed to simulate total dry matter of the crops grown under dry condition (W2 and W3), particularly after day 76 in 1989 and day 101 in 1990 season. This is particularly because the model failed to simulate the growth of the storage organ at later stage of pod-filling.

It is also possible to conclude that the accuracy of the model to predict crop water use was acceptable for particular purpose of this study. The overall results of the experimentation with the model suggest that the model simulates crop water use from season to season under different moisture regimes reasonably well.

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