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Regulation of Drought Tolerance in Beans

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I. EXECUTIVE SUMMARY

A series of experiments were conducted to determine genotypic variations and potential for drought tolerance in common bean (*Phaseolus vulgaris*). A group of drought susceptible or drought tolerant genotypes of bean were grown at different water stress conditions to compare final yield and other biochemical and physiological characteristics. Drought was imposed by withholding water for various durations after which plants were rewatered and allowed to grow to maturity for harvest. Treatment effects on plant growth and development, seed yield, time of flowering, flower number, pod number, seeds per pod, pods per plant, fresh and dry weights of seeds (100) and other yield components were recorded. In addition, physiological indicators for tolerance such as water potential, osmotic potential, relative water content, potassium and proline content of leaves were also monitored during water stress. With the development of water deficits, water potential and osmotic potential decreased in all genotypes. Estimated pressure potential did not significantly change in the drought-tolerant genotypes and the relative water content remained constant in some tolerant genotypes. While free proline accumulated in the leaves of all genotypes, surprisingly, the greatest increases in proline occurred in the drought-susceptible genotypes. Proline accumulation accounted for a decrease of up to 0.48 MPa in the osmotic potential in some tolerant genotypes. However, not all genotypes showed the expected decreases in osmotic potential despite the great increases in leaf proline content. Overall the results suggest that although proline accumulation is a stress-induced response, it may not be a suitable indicator (physiological criterion) for screening and identifying drought-tolerant genotypes. Reduction in total growth and seed yield and other yield parameters occurred in all genotypes grown under drought stress. Other than yield, no clear indications of differences between tolerant and susceptible genotypes were found in many other characteristics. In selection of bean genotypes for drought tolerance final yield, as principal criterion, appears to be the most direct and reliable parameter.

These considerations are being taken into account in other drought projects recently initiated in Honduras and in the Central American region. Bean research program at Zamarano School of Agriculture continues in its efforts to improve beans for tolerance to drought in collaboration with the Universities of Minnesota and Puerto Rico, CIAT and the regional program ProFrijol. The expertise acquired under this project are being used to design and implement better programs.

II. PROJECT OBJECTIVES

Objective I. To monitor the genotypic potential of beans under reduced soil water content.

Objective II. To determine capacity of osmotic adjustment in tolerant genotype.

Objective III. To identify internal constituents associated with tolerance.

III. MATERIALS AND RESULTS

A. Group 1. Experiments were conducted in a greenhouse or in the field. In the greenhouse plants were grown in PVC pipes (5" diameter x 30" long) filled with a growth medium which consisted of soil and perlite (4:1). Soil characteristics were sandy loam, pH 5.3, O.M. 2.1%, N total 0.18%, P 25 ppm and K 371 ppm. The soil was fertilized with 18-46-0 fertilizer, before mixed with the perlite. A foliar fertilizer solution (Bayfolan^R) was sprayed to plants at 20, 30 and 40 days after planting (DAP). Two plants per each experimental unit were left after thinning at 10 DAP.

All germplasms were from the CIAT (International Center for Tropical Agriculture) collections in Columbia including BAT 477, Danli 46 and San Cristobal 86 (drought tolerant) and A70, Porrillo Sentético and RAB 50 (drought susceptible).

Plants were irrigated every day at 9-10 am, to bring the soil moisture to maximum field capacity. Irrigation continued until physiological maturity, or until sampling began. One group of plants was subjected to stress by withholding irrigation every other day (at 20, 22, 24 and 26 DAP), followed by three day intervals (at 29, 32 and 35 DAP), and finally at five day intervals (at 40, 45 and 50 DAP). Due to the limited water withholding capacity of the medium in the PVC pipes, stress was not continuous (to avoid rapid and unphysiological conditions).

Determinations in these controlled experiments were leaf water potential (LWP), measured on first fully-developed trifoliate leaf samples with a Model 300 Plant Water Status Consol (Soil-Moisture Equipment Co., Calif.), percentage of water loss (PWL) by exposing leaflet samples from second fully-developed trifoliate leaves to room temperature in an air conditioned lab (about 25°C) for 24 hours (Walker and Miller, 1986), root length and volume, leaf, shoot, root and pod dry weights, and shoot root:ratio. In some experiments phenological data, such as days to flowering and to maturity, and yield components (pods/plant, seeds/pod and seed size), as well as yield were recorded.

Three experiments were conducted during the dry months in the field. Soil characteristics were those indicated for greenhouse studies. Land preparation consisted in conventional plowing and harrowing. The field had received a subsoil plowing. Experimental plots consisted of two 5 m rows. Treatments were two watering levels and eight genotypes distributed in a split plot design. Control plants were irrigated approximately once a

week for eight weeks; stressed plants were irrigated three times, the last irrigation 14 DAP. Plants were fertilized with 250 kg/ha of 18-46-0 at planting and 50 kg/ha of Urea 15 DAP. Planting distance was 0.60 m between rows and 0.10 m within rows, approximately 166,666 pl/ha. Disease and insect pests were controlled using recommended pesticides. Weeds were controlled with preplant incorporated herbicides and manual weeding during growth.

Days to flowering and to physiological maturity, number of fully developed and empty pods per plant, seeds per pod, 100 seeds dry weight, seed yield *per se*, leaf, stem, root dry weights, root volume and drought susceptibility index were determined.

Experiment 1

This experiment consisted of two moisture treatments (control and stress) and six genotypes, three tolerant (San Cristobal 83, BAT 477 and Danlí 46), and three susceptible (A70, BAT 1224 and Porrillo Sintético), and two common tepari hybrid bean lines (M3 and Q3-SI-1), distributed in a split plot design with four replications. Plants grown in PVC pipes were harvested at 43 DAP (flowering stage) and LWP, PWL, LDW, root length and volume and total plant dry weight were determined.

Significant PWL values were observed on leaf samples from water stressed plants; no differences between genotypes were found. Similarly, lower PWL values were registered on detached leaf samples from stressed plants after 6, 10 and 24 hours at room temperature. Significant PWL differences between genotypes were observed after 24 hours; San Cristobal 83 and A70, tolerant and susceptible, respectively, having the higher PWL mean values. After exposing the same samples used for PWL determinations for 24 additional hours at 65°C in an open, no differences were observed in LDW under different moisture or genotypes treatments (Table 1).

Differences in total plant dry weight were only observed between moisture treatments. No differences for root length were observed in control vs. stressed plants or between genotypes. However, genotypic differences were observed for root volume; interestingly enough, a susceptible genotype BAT 1224 had the largest root volume, although not significantly different with values from two tolerant genotypes.

In all cases, LWP, PWL, and total plant dry weight declined in stressed plants. Only two significant differences between genotypes were observed, PWL after 24 hours and root volume; however, these differences did not provide evidence for drought tolerance (Table 1).

Experiment 2

Experiment 2 was a continuation of experiment 1 and overlapped with experiment 1. The experiment included the same moisture and genotype treatments using a split plot design following the same

procedures. However, this experiment was carried out until physiological maturity, and additional determinations on plant growth and seed yield parameters were made.

Moisture treatment were observed affecting stressed plants which flowered and matured later than control plants; also, plants grown under stress had lower total plant and seed dry weights (Table 2). On the other hand, genotypic effects were only observed in total plant dry weight, where two susceptible and one tolerant genotypes had the highest values, and number of seeds/pod with susceptible plants having more seeds than tolerant ones. No significant interactions were observed.

Experiment 3

Experiment 3 was initiated to reconfirm results obtained from previous experiments. Similar experimental treatments and procedures than the previous two experiments were used. In this experiment, all parameters observed in Experiment 1 and 2 were determined in a single experiment by harvesting two sets of plants, one set at flowering for measuring LWP, PWL and LDW, and the other set harvested at physiological maturity to determine leaf, stem, root and total plant dry weights, root length and volume, pods/plant seeds/pod, 100 seeds dry weight and seed yield/plant, and to estimate the drought susceptibility index and yield differential.

No differences were observed for phenological characteristics (Table 3). LWP values were higher on stressed than control plants and certain genotypic differences were observed; however, these were mixed results. The PWL was significantly lower in stressed plants after 2, 6, 10 and 24 hours, but no differences between genotypes were observed. Both tolerant and susceptible genotypes had higher leaf dry weights (Table 4).

Differences in plant parts and total plant dry weights were affected by moisture treatments (Table 5). Similar results were observed for root length, pods/plant seed/pod, 100 seeds dry weight and seed dry weight/plant. Differences between genotypes were observed for seed/pod and seed yield, but again no differences were observed between genotypes. Significant correlations with seed yield were found for leaf, stem, root and total plant dry weights, root volume, and yield components (Table 5). Drought/genotype interaction was significant for seed yield. Extremely good performance under control, but very poor yield under stress were obtained in genotypes Danlí 46 and A70; whilst in other genotypes, such as BAT 477, no major effects of moisture treatments in seed yield
were observed (Table 6).

Experiment 4

An additional experiment in the greenhouse was conducted in 1990. This time only two genotypes, one tolerant, San Cristobal 83, and one susceptible, A70, were grown under two moisture treatments,

control and stress, using PVC pipes and similar soil medium. Experimental units were distributed in a split-plot design using five replications. LWR, RWL, LWP and dry weights of leaves, shoots and roots were measured on samples taken at 43 DAP (flowering stage).

No differences in LDW were observed after leaf detachment in determinations made from 0 to 24 hours. However, A70 had significantly larger leaf weights at 0 and 2 hours. On the other hand, the PWL was only significantly affected by moisture treatment. Although PWL was lower under stress (only after 2 h); no differences were observed between genotypes (Table 7). However, plants grown under stress had lower LWP and larger root dry weight, and significantly lower shoot:root ratio than control plants. Significantly lower LWP, larger leaf and shoot dry weights were observed in the susceptible genotype A70 (Table 8). Again the results are inconclusive; however the LWP in San Cristobal 83 was significantly higher than A70 indicating greater tolerance to water stress. Nevertheless, this result does not explain why these tolerant plants had larger leaf and shoot dry weight.

Experiment 5

This experiment included the same genotypes and hybrid lines from experiment 3, was initiated under control and stress moisture conditions. Information on the time (DAP) of flower bud formation and number, days to flowering and flower number, days to and number of pods initiated and fully developed, days to maturity, root length and volume, LWP and leaf, stem, and root dry weights, were taken from plants grown on PVC pipes containing a soil:perlite medium.

Plants grown under water stress had significantly lower number of fully developed pods, root volume and leaf, stem and root dry weights. Differences between genotypes were found for days to flower bud, days to flowering, days to pod initiation and days to full pods, days to maturity, root length, LWP and leaf dry weight (Table 9). The earliest materials on days to flower bud, flowering, pod initiation and physiological maturity were the two hybrid lines M3 and Q3-SI-1. A70, supposedly a susceptible genotype, had larger number of fully developed pods, roots and leaf dry weight than the tolerant genotype San Cristobal 83.

Experiment 6

Experiment 6 was conducted in the field and included three tolerant (San Cristobal 83, BAT 477 and Danlí 46) and three susceptible (A70, BAT 1224 and Porrillo Sintético) common bean genotypes, and two common x tepari bean lines (M3 and T3-SI-1). Total moisture in stress plots was 225.4 mm and in control plots 542.2 mm using a sprinkler irrigation system. The experiment was conducted using a split plot design with four replications; moisture treatments were distributed on main plots and genotypes

on sub-plots.

Plants grown under water stress had significantly lower number of fully developed pods per plant, seeds per pod, 100 seeds dry weight, seed yield, leaf, stem and root dry weights, and root volume (Table 10). Differences between genotypes in days to flowering and to physiological maturity, number of fully developed pods, seeds/pod, seeds dry weight, seed yield, leaf, stem and root dry weights and root volume, did not give any clear indication of being associated with tolerance. Significant moisture/genotype interactions were found in days to flowering and to maturity, and in leaf, stem and root dry weights; some genotypes being less affected by drought than others (Table 10). Seed yields and drought susceptibility index suggested that certain genotypes such as BAT 477 and Danlí 46, were less affected; the highest yield under drought was obtained in Danlí 46 (Table 11).

Experiment 7

Fourteen bean genotypes, including three tolerant (San Cristobal 83, BAT 477 and Danlí 46) and three susceptible (A70, BAT 1224 and Porrillo Sintético) genotypes were grown in the field under well watered or stress moisture conditions using a sprinkler irrigation system. The other additional eight bean genotypes included improved lines and commercial varieties. The experiment was established, using a split plot design; moisture treatments were distributed as main plots and genotypes as sub-plots.

Stressed plants had significantly fewer fully developed pods/plants seeds/pod and seed yield, than controls. On the other hand, there were differences between genotypes on days to flowering and to physiological maturity, number of fully developed and empty pods/plant, seeds dry weight and seed yield. Significant interactions were observed for days to flowering and to physiological maturity, and number of fully developed and empty pods per plant (Table 12).

Three commercial varieties from Honduras (improved landraces), Chingo R, Desarrural 1R and Cuarenteño, and two Mexican lines, Canario 107 and FM RMC, showed the earliest days to flowering. Days to flowering and to physiological maturity were not affected by moisture treatments in some genotypes but were affected in others. On the other hand, some genotypes showed slightly lower yield reduction in stress plots (lower drought susceptibility index). The highest yield under drought stress were recorded in Danlí 46, a tolerant genotype, and in CNF 480, a line with excellent field performance in Brazil (Table 12).

Experiment 8

This field experiment included fifteen bean genotypes was established in a split plot design with four replications. Moisture treatments were applied using a sprinkler irrigation system.

Stressed plants matured slightly later, had more empty pods, less seeds/pod and lower seeds dry weight and yield. Differences between genotypes were observed for days to flowering and to physiological maturity, number of fully developed and empty pods, seeds/pod, seed dry weight and yield. Significant moisture/genotype interactions were found for a number of fully developed pods/plant, seeds dry weight and yield (Table 13). The earliest days to flowering and to maturity were observed in three Honduras improved landraces, Chingo R, Desarrural 1R and Cuarenteño, and two lines from México, Canario 107 and FM RMC (Table 14).

Some of the earliest materials (Chingo R, Desarrural 1R and Canario 107) had the lowest drought susceptibility index (Table 15), suggesting the advantage of earliness under drought stress conditions. However, these values were high because of their poor performance under more favorable moisture (control) conditions, showing certain weaknesses of using this index to identify tolerant materials. The highest seed yield under stress were obtained in Desarrural 1R as well as in BAT 477. Using final yield, BAT 477 would be considered drought tolerant in spite of having a higher drought susceptibility index than some other genotypes.

Table 1. Leaf water potencial (LWP), percentage of water loss (PWL), leaf dry weight (LDW), total plant dry weight, and root lenght and volume from six common bean genotypes and one common x tepari interspecific hybrid line grown under control and stress moisture conditions.

Treatment	LWP (bars)	PWL[Y] 2	PWL[Y] 6	PWL[Y] 10	PWL[Y] 24	LDW[Z] (g/pl) 0	LDW[Z] (g/pl) 48	Total plant dry wt (g)	Root Lenght (cm)	Root Volume (cc)
Condition (A)										
Control	10.4	5.8	13.1	24.4	35.9	3.05	2.00	16.3	72.6	34.5
Stress	8.8	3.7	8.5	12.9	24.5	2.78	2.12	11.0	77.7	31.4
Anova	**	ns	**	**	**	ns	ns	**	ns	ns
LSD (0.05)	1.2	-	3.4	6.8	7.9	-	-	5.2	-	-
Genotype (B)										
San Cristobal	11.2	5.6	12.1	21.4	37.5	2.58	1.62	14.1	70.7	35.4
BAT 477	10.0	4.7	10.4	16.2	29.3	3.46	2.47	13.1	87.9	34.4
Danlí 46	8.6	5.5	11.7	17.3	31.6	2.57	1.81	13.9	80.0	25.0
A70	10.1	4.4	12.6	19.3	35.4	3.09	2.00	12.9	64.6	25.1
BAT 1224	9.4	4.6	10.3	15.2	27.1	2.68	1.97	14.8	76.6	44.3
Porrillo Sint.	9.6	4.6	9.3	13.7	25.1	2.95	2.21	12.7	68.5	26.0
M3 (hybrid)	8.5	4.0	9.2	13.6	25.3	3.18	2.33	13.9	77.4	40.5
Anova	ns	ns	ns	ns	**	ns	ns	ns	ns	**
LSD (0.05)	-	-	-	-	8.4	-	-	-	-	14.3
Interaction										
A x B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[Y] Percentage of water loss after 2, 4, 6, 10 y 24 hours at room temperature.
[Z] Leaf dry weight (24 additional hours at 65°C).
** and ns Significant at $P \leq 0.05$ and non-significant, respectively.

Table 2. Differences on bud, flower, pod formation and maturity, leaf, pods, stem, root and total dry weight, yield components and harvest index from six common bean genotypes and one common x tepari interspecific hybrid line grown under control and stress moisture conditions.

Treatment	Flower bud (days)	Flowering		Pods Initiated		Pods Formed	Maturity days	Dry wt (g/pl)					Pods per plant	Seeds per pod	Seed yield (g/pl)	Harvest index
		Days	No.	Days	No.	Days		Leaf	Pods	Stem	Root	Total				
Condition (A)																
Control	29	32	2.1	35	2.8	40	59	4.5	4.1	4.8	2.0	23.4	13.8	3.5	8.31	0.4
Stress	30	34	2.2	37	2.7	41	62	2.4	2.4	2.4	1.5	12.6	10.0	3.1	3.85	0.3
Anova	ns	**	ns	ns	ns	ns	**	ns	ns	ns	ns	**	ns	ns	**	ns
LSD (0.05)		2.0					1.6	-	-	-	-	6.5	-	-	3.69	-
Genotype (B)																
San Cristobal	30	33	2.5	36	2.7	40	61	2.1	2.4	2.5	1.1	13.3	10.5	3.0	6.09	0.5
BAT 477	31	34	1.5	37	2.5	41	61	3.3	3.4	2.9	1.9	18.5	11.8	3.8	6.94	0.4
Danlí 46	30	34	2.2	38	2.7	42	61	2.2	3.6	2.5	1.7	16.4	14.2	2.7	6.47	0.4
A70	30	34	2.0	38	3.2	42	60	4.8	3.0	4.5	2.1	20.2	8.8	4.2	5.87	0.3
BAT 1224	29	33	3.7	36	2.8	40	60	2.8	2.7	4.2	2.8	19.8	10.5	4.0	7.14	0.4
Porrillo Sint.	30	33	1.5	37	2.8	40	60	5.2	4.3	5.1	1.7	21.8	13.2	3.7	5.35	0.3
M3 (hybrid)	28	30	2.0	33	2.5	39	59	3.8	3.1	3.5	1.1	15.7	14.0	2.0	4.71	0.3
Anova	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**	ns	**	ns	ns
LSD (0.05)	-	-	-	-	-	-	-	-	-	-	-	5.4	-	1.4	-	-
Interaction																
A x B	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

** and ns Significant at $P \leq 0.05$ and non-significant, respectively.

Table 3. Differences on bud, flower and pod formation and physiological maturity from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

Treatment	Flower bud (days)	Flowering		Pods				Maturity days
				Initiated		Formed		
		Days	No.	Days	No.	Days	No.	
Condition (A)								
Control	31	36	2.7	37	3.6	47	4.2	66
Stress	31	36	3.2	37	4.6	47	3.4	64
Anova	ns	ns	ns	ns	ns	ns	ns	ns
Genotype (B)								
San Cristobal	30	35	2.0	36	3.1	49	3.3	68
BAT 477	33	38	3.4	39	4.9	49	2.5	66
Danlí 46	32	37	2.9	39	3.6	49	2.9	68
A70	32	37	3.4	38	5.8	48	3.1	66
BAT 1224	33	38	3.0	39	4.8	48	6.0	66
Porrillo Sint.	33	37	1.6	38	3.0	48	4.0	65
M3 (hybrid)	27	31	3.4	33	4.0	42	4.8	57
Q3-SI-1 (hybrid)	28	34	3.9	34	3.5	45	3.9	63
Anova	*	*	ns	*	ns	*	ns	*
LSD (0.05)	1.6	2.4	-	2.0	-	2.4	-	2.5
Interaction								
A x B	ns	ns	ns	ns	ns	ns	ns	ns

* and ns Significant at $P \leq 0.01$ and non-significant, respectivily.

Table 4. Leaf water potencial (LWP), percentage of water loss (PWL) and leaf dry weight (LDW) from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

Treatment	LWP (bars)	PWL[Y] 2	6	10	24	48	LDW[Z] (g/pl) 0	48
Condition (A)								
Control	10.1	18.2	34.0	44.0	68.2	82.2	1.31	0.23
Stress	13.9	8.1	20.7	27.7	48.8	82.2	1.09	0.19
Anova	*	**	*	*	*	ns	ns	ns
LSD (0.05)	1.4	7.7	3.9	4.3	7.9	-	-	-
Genotype (B)								
San Cristobal	10.9	13.6	26.3	34.7	57.4	83.0	0.98	0.16
BAT 477	10.9	6.7	23.6	37.0	58.7	80.6	1.37	0.26
Danlí 46	14.0	15.4	30.6	40.2	62.8	82.9	1.33	0.21
A70	10.8	10.3	21.8	29.9	53.6	80.1	1.64	0.31
BAT 1224	12.9	15.9	28.3	36.0	57.7	82.1	0.99	0.17
Porrillo Sint.	13.5	14.7	27.2	35.6	58.2	82.4	0.99	0.17
M3 (hybrid)	11.1	13.4	25.3	33.0	55.4	83.0	1.28	0.22
Q3-SI-1 (hybrid)	11.6	15.2	30.5	40.4	64.1	83.3	1.01	0.15
Anova	*	ns	ns	ns	ns	ns	ns	*
LSD (0.05)	2.1	-	-	-	-	-	-	0.09
Interaction A x B	ns	ns	ns	ns	ns	ns	ns	ns

[Y] Percentage of water loss after 2, 4, 6, 10 y 24 hours at room temperature, and 48 hours (after 24 additional hours at 65°C).
[Z] Leaf dry weight (24 additional hours at 65°C).
*,** and ns Significant at P≤ 0.01, 0.05 and non-significant, respectively.

Table 5. Differences on leaf, stem, root and total dry weight, root length and volume, and yield components from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

Treatment	Dry wt (g/pl)				Root		Pods per plant	Seeds per pod	Seed size (g)	Seed yield (g/pl)
	Leaf	Stem	Root	Total	Lenght (cm)	Volume (cc)				
Condition (A)										
Control	3.0	1.4	1.5	6.3	64.8	32.7	6.3	4.8	0.19	5.39
Stress	2.2	1.0	1.2	4.6	74.2	29.9	4.7	4.1	0.15	2.48
Anova	**	*	**	*	**	ns	*	**	**	*
LSD (0.05)	0.6	0.2	0.2	0.9	7.2	-	0.6	0.4	0.03	1.3
Genotype (B)										
San Cristobal	2.4	1.1	1.4	5.1	67.3	32.2	5.4	3.7	0.19	3.73
BAT 477	2.7	1.0	1.4	5.7	64.4	30.7	3.7	4.7	0.14	2.99
Danlí 46	2.7	1.1	1.6	5.8	72.8	34.2	6.2	5.2	0.15	5.17
A70	2.9	1.3	1.4	6.2	70.4	31.3	6.2	3.8	0.23	4.93
BAT 1224	2.5	1.0	1.2	4.9	71.9	33.4	5.4	4.0	0.16	3.07
Porrillo Sint.	2.9	1.3	1.4	5.9	67.0	30.1	4.8	5.5	0.15	3.34
M3 (hybrid)	2.3	1.3	1.1	5.2	71.1	31.3	6.3	4.3	0.19	4.66
Q3-SI-1(hybrid)	2.3	1.2	1.1	5.0	71.1	27.3	5.7	4.6	0.17	3.58
Anova	ns	ns	ns	ns	ns	ns	ns	**	**	**
LSD (0.05)	-	-	-	-	-	-	-	0.9	0.03	1.61
Interaction										
A x B	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
LSD(0.05)	-	-	-	-	-	-	-	-	-	2.18
Correlation[z]	0.5	0.5	0.4	0.5	0.0	0.3	0.7	0.4	0.7	
Signif.	*	*	*	*	ns	**	*	*	*	

[z] Correlation with seed yield/pl.
*, ** and ns Significant at P≤ 0.01, 0.05 and non-significant, respectively.

Table 6. Mean values of seed yield under control and stress conditions, drought susceptibility index and diferential yield from six common genotypes and two common x tepari interspecific hybrid lines.

Genotype	Seed yield[Z] (g/pl) Control	Stress	Drought susceptibility index[Y]	Diferential yield[X]
San Cristobal	4.78	2.68	0.74	40.1
BAT 477	3.68	2.31	0.62	33.2
Danlí 46	8.62	1.73	1.50	80.8
A70	7.07	2.78	1.08	58.1
BAT 1224	3.94	2.19	0.77	41.3
Porrillo Sint.	4.40	2.27	0.80	43.3
M3 (hybrid)	5.89	3.43	0.72	38.6
Q3-SI-1 (hybrid)	4.73	2.43	0.87	47.2
Average	5.39	2.48	0.89	45.3
Anova	**	ns	**	**
LSD(0.05)	2.94	-	0.45	24.5

[X] DY= ((yield control-yield stress)/yield stress)*100.
[Y] DSI= (1-(yield stress/yield control))/(1-(average yield stress/average yield control)).
[Z] Dry wt seeds/plant.
** and ns Significant at $P \leq 0.05$ and non-significant, respectively.

Table 7. Variation over time of leaf dry weight and percentage of water loss from detached leaves from two common bean genotypes grown under control and stress conditions.

Factor	Time (hours) after leaf detachment[z]							
	0	2	4	6	8	10	12	24
	Leaf dry weight (g/pl)							
Condition								
Control	1.97	1.84	1.73	1.61	1.50	1.38	1.06	0.94
Stress	1.79	1.71	1.62	1.52	1.43	1.33	1.06	0.95
Signif.	ns	ns	ns	ns	ns	ns	ns	ns
Genotype								
San Crist.83	1.65	1.56	1.47	1.36	1.28	1.18	0.92	0.82
A-70	2.10	2.00	1.89	1.76	1.67	1.53	1.20	1.07
Signif.	*	*	ns	ns	ns	ns	ns	ns
	Percentage of water loss (%)							
Condition								
Control	0	7.6	14.3	22.0	28.5	35.9	55.2	62.5
Stress	0	5.5	11.8	18.7	24.6	31.3	49.3	57.1
Signif.	-	**	ns	ns	ns	ns	ns	ns
Genotype								
San Crist.83	0	6.8	13.2	20.5	26.6	33.6	51.9	59.5
A-70	0	6.3	12.9	20.3	26.4	33.6	52.5	60.0
Signif.	-	ns	ns	ns	ns	ns	ns	ns

[z] Measured at room teperature.
*, ** and ns Significant at $P < .05$, .01 and non-significant, respectively. All interactions were non-significants.

Table 8. Leaf water potential (LWP) and leaf, shoot and root dry weights from two common bean genotypes grown under control and stress conditions.

Factor	LWP (bars)[z]	Dry weight (g/plant) Leaf	Shoot(S)	Root(R)	S/R Ratio
Condition					
Control	8.6	0.29	2.48	0.58	4.28
Stress	6.5	0.28	2.26	1.17	1.93
Signif.	*	ns	ns	**	**
Genotype					
San Crist.	9.3	0.25	2.03	0.74	2.74
A-70	5.6	0.33	2.70	1.00	2.70
Signif.	**	**	**	ns	ns

[z] Leaf water potential from samples of the entire first fully-developed trifoliate leaf samples.

*, ** and ns Significant at P< .05, .01 and non-significant, respectively. All interactions were non-significants.

Table 9. Differences on bud flower, flowering and pod formation and physiological maturity, root length and volume, leaf water potential (LWP), and leaf, stem, and root dry weigths from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

	Flower bud formation		Flowering		Pods Initiated		Pods Formed		Maturity	Root Length	Root Vol	LWP	Dry wt (g/pl)		
	Days	No.	Days	No.	Days	No.	Days	No.	days	(cm)	(cc)	(bars)	Leaf	Stem	Root
Condition (A)															
Control	32	9.3	37	2.9	39	2.8	47	4.0	56	61	40	11.6	1.93	1.24	2.45
Stress	33	9.2	38	2.4	41	1.7	49	2.3	56	73	19	15.9	1.05	0.66	1.39
Anova	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	**	ns	**	*	**
LSD (0.05)	-	-	-	-	-	-	-	1.2	-	-	13.0	-	0.50	0.26	0.91
Genotype (B)															
San Cristóbal 83	31	9.3	36	2.3	39	1.9	48	3.3	57	63	20	13.4	1.22	0.74	1.64
BAT 477	37	7.0	41	2.0	45	1.5	51	3.0	56	69	32	13.4	1.57	0.91	2.06
Danlí 46	35	10.5	39	3.0	43	2.9	51	2.8	57	81	37	14.5	1.82	1.06	2.09
A70	34	11.3	39	3.8	42	3.4	48	4.9	56	78	35	12.7	1.78	1.12	1.92
BAT 1224	36	7.0	40	2.1	43	1.9	50	1.5	56	58	31	15.4	1.50	0.82	2.46
Porrillo Sint.	34	8.4	38	1.8	41	2.3	49	3.5	57	68	33	14.4	1.60	1.09	1.96
M3 (hybrid)	25	9.3	31	2.6	33	2.6	42	3.0	52	61	25	14.0	1.21	1.03	1.36
Q3-SI-1 (hybrid)	28	10.6	34	3.1	36	2.0	46	3.1	55	55	24	12.1	1.24	0.84	1.85
Anova	*	ns	*	ns	*	ns	*	*	*	*	ns	**	**	ns	ns
LSD (0.05)	2.6	-	2.6	-	3.2	-	2.1	1.1	0.8	13.4	-	2.0	0.43	-	-
Interaction															
A x B	ns	ns	ns	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns
LSD (0.05)	-	-	-	-	-	-	-	1.6	1.2	-	-	-	-	-	-

*, ** and ns Significant at $P \leq 0.01$, 0.05 and non-significant, respectively.

Table 10. Differences on days to flowering (DF) and to maturity (DM), yield components, leaf, stem, root dry weight, and root volume from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

	DF	DM	Pods per plant Fully	Pods per plant Empty	Seeds per pod	100 seeds dry wt (g)	Seed yield (kg/ha)	Dry wt (g/pl) Leaf	Dry wt (g/pl) Stem	Dry wt (g/pl) Root	Volume root (cc)
Condition (A)											
Control	40	76	14	0.9	5	16.9	2299	3.68	2.42	0.86	5.4
Stress	41	77	11	0.6	4	14.8	995	2.39	1.40	0.59	2.5
Anova	ns	ns	**	ns	*	*	*	*	*	*	*
LSD (0.05)	-	-	2.6	-	0.3	0.5	434	0.58	0.49	0.13	0.7
Genotype (B)											
San Cristóbal 83	41	78	14	0.9	4	15.5	1764	2.66	1.71	0.68	3.3
BAT 477	45	77	10	0.5	5	14.5	1538	3.02	1.50	0.66	4.3
Danlí 46	43	75	12	0.8	5	15.4	1733	3.02	1.73	0.79	4.2
A70	41	75	12	0.4	4	17.7	1644	3.50	2.28	0.66	3.6
BAT 1224	45	76	12	0.7	5	15.1	1724	3.01	1.92	0.89	4.7
Porrillo Sint.	44	78	13	0.3	5	16.4	1702	2.62	1.68	0.78	4.0
M3	31	74	14	0.7	5	16.2	1794	3.41	2.71	0.72	4.0
T3-SI-1	37	79	11	1.6	4	16.0	1277	3.04	1.77	0.62	3.5
Anova	*	*	*	ns	*	*	**	*	*	*	*
LSD (0.05)	1.0	0.8	2.0	-	0.5	1.1	321	0.52	0.38	0.10	0.7
Interaction											
A x B	**	*	ns	ns	ns	**	ns	**	*	**	ns
LSD (0.05)	1.4	1.2	-	-	-	1.6	-	0.73	0.54	0.14	-

*, **, ns Significant at P≤ 0.01, 0.05 and non-significant, respectivily.

Table 11. Differences on days to flowering and to maturity, seed yield and drought susceptibility index from six common bean genotypes and two common x tepari interspecific hybrid lines grown under control and stress moisture conditions.

Genotype	Days flowering		Days maturity		Seed yield (kg/ha)Z		Drought susceptib. index[Y]
	Control	Stress	Control	Stress	Control	Stress	
San Cristóbal 83	39	42	77	80	2568	960	1.1
BAT 477	45	45	78	76	1993	1084	0.7
Danlí 46	42	44	74	75	2173	1294	0.6
A 70	41	41	74	75	2264	1023	0.9
BAT 1224	44	46	77	75	2439	1009	0.8
Porrillo Sintético	43	45	78	79	2416	989	1.0
M3	32	31	73	75	2552	1035	1.0
T3-SI-1	36	37	77	80	1983	570	1.2
Anova	*	*	*	*	ns	*	**
LSD (5%)	1.3	1.4	1.3	1.2	-	214	0.4

[Z] Total moisture provided by sprinkler irrigation. Last irrigation on stress plots at 14 days after planting.

[Y] DSI= (1-(yield stress/yield control))/(1-(average yield stress/average yield control)).

*, ** and n.s. Significant at P< 0.01, 0.05 and non-significant, respectively.

Table 12. Differences on days to flowering (DF) and to maturity (DM), and yield components from fourteen common bean genotypes grown under control and stress moisture conditions.

	DF	DM	Pods per plant Fully	Pods per plant Empty	Seeds per pod	100 seeds dry wt (g)	Seed yield (kg/ha)
Conditon (A)							
Control	39	75	14	0.6	5	16.9	2250
Stress	40	76	8	0.8	4	14.8	668
Anova	ns	ns	**	ns	*	ns	**
LSD (0.05)	-	-	4.6	-	0.3	-	1159
Genotype (B)							
San Cristóbal 83	41	76	11	0.6	4	14.4	1359
BAT 477	45	78	12	0.7	5	14.4	1841
Danlí 46	43	75	13	1.2	5	14.0	1823
A70	41	76	11	0.5	4	17.5	1297
BAT 1224	45	76	9	0.7	5	14.2	1263
Porrillo Sint.	43	75	12	0.5	4	16.2	1950
DOR 364	43	76	15	0.6	5	15.5	1914
Chingo R	32	74	12	0.5	4	13.9	1188
Desarrural 1R	32	73	9	0.2	4	18.4	1237
Cuarenteño	34	74	13	0.7	4	13.9	1293
CNF 480	40	76	13	0.5	4	19.5	1721
Canario 107	33	71	7	2.3	3	19.6	891
FM RMC	33	75	10	0.9	4	17.0	1009
Icta Ostúa	43	76	11	0.2	5	13.3	1639
Anova	*	*	*	**	*	*	*
LSD (0.05)	1.7	1.4	3.0	1.0	1.1	2.7	487
Interaction							
A x B	*	*	*	*	ns	ns	*
LSD (0.05)	2.4	1.9	4.3	1.4			689

*, **, ns Significant at $P \leq 0.01$, 0.05 and non-significant, respectivily.

Table 13. Differences on days to flowering and to maturity, seed yield and drought susceptibility index from fourteen common bean genotypes grown under control and stress moisture conditions.

Genotype	Days flowering		Days maturity		Seed yield (kg/ha)[z]		Drought susceptib. index[y]
	Control	Stress	Control	Stress	Control	Stress	
San Cristóbal 83	40	42	77	75	2007	712	0.9
BAT 477	44	47	79	77	3078	605	1.1
Danlí 46	42	45	75	75	2703	943	0.9
A70	41	41	75	76	1777	817	0.7
BAT 1224	45	44	77	74	1847	680	0.9
Porrillo Sintético	41	46	75	75	3389	511	1.2
DOR 364	41	45	77	76	2966	862	0.9
Chingo R	33	31	73	75	1885	490	1.0
Desarrural 1R	33	32	72	74	1732	742	0.8
Cuarenteño	34	33	73	75	1949	636	0.9
CNF 480	40	40	76	77	2458	984	0.8
Canario 107	32	33	67	76	1461	321	1.1
FM RMC	33	33	74	76	1656	362	1.1
Icta Ostúa	43	44	76	76	2595	683	1.1
Anova	*	*	*	**	*	*	ns
LSD (5%)	2.7	2.1	2.2	1.7	941	331	

[z] Total moisture provided by sprinkler irrigation. Last irrigation on stress plots at 14 days after planting.

[y] DSI= (1-(yield stress/yield control))/(1-(average yield stress/average yield control))

*, ** and ns Significant at P< .01, .05 and non-significant, respectively.

Table 14. Differences on days to flowering (DF) and to maturity (DM), and yield components from fifteen common bean genotypes grown under control and stress moisture conditions.

	DF	DM	Pods per plant Fully	Pods per plant Empty	Seeds per pod	100 seeds dry wt (g)	Seed yield (kg/ha)
Conditon (A)							
Control	41	69	11	0	5	21.4	1976
Stress	40	70	8	1	4	18.4	794
Anova	ns	**	ns	**	**	*	**
LSD (0.05)	-	0.5	-	0.3	0.9	0.5	702
Genotype (B)							
San Cristóbal 83	41	75	11	1	5	18.1	1348
BAT 477	43	73	12	0	5	18.1	2122
Danlí 46	44	74	10	1	5	18.3	1283
A70	43	73	9	1	4	20.0	1407
BAT 1224	44	74	13	1	5	18.1	1842
Porrillo Sint.	44	74	11	0	4	20.8	1595
DOR 364	43	73	11	0	4	18.4	1580
Chingo R	36	59	9	1	5	17.7	1073
Desarrural 1R	36	59	7	0	5	21.7	1034
Cuarenteño	36	60	8	0	3	17.8	977
CNF 480	40	72	10	1	5	23.0	1840
Canario 107	34	62	6	2	3	27.7	817
FM RMC	36	70	9	1	4	20.5	1078
Icta Ostúa	44	75	10	0	4	19.2	1431
DOR 482	43	73	10	0	5	18.7	1350
Anova	*	*	*	*	*	*	*
LSD (0.05)	1.3	3.2	2.9	0.6	1.1	1.6	510
Interaction							
A x B	ns	ns	*	ns	ns	*	*
LSD (0.05)	-	-	4.1	-	-	2.3	721

*, **, ns Significant at P≤ 0.01, 0.05 and non-significant, respectivily.

Table 15. Differences on days to flowering and to maturity, seed yield and drought susceptibility index from fifteen common bean genotypes grown under control and stress moisture conditions.

Genotype	Days flowering		Days maturity		Seed yield (kg/ha)[z]		Drought susceptib. index[y]
	Control	Stress	Control	Stress	Control	Stress	
San Cristóbal 83	42	40	75	75	2016	679	1.1
BAT 477	42	44	74	72	2951	1293	0.9
Danlí 46	44	44	72	75	1873	692	1.0
A70	43	44	71	76	2188	627	1.2
BAT 1224	45	44	74	74	2684	999	1.0
Porrillo Sintético	43	44	72	76	2687	504	1.3
DOR 364	44	42	72	75	2487	672	1.1
Chingo R	36	35	59	59	1242	904	0.4
Desarrural 1R	36	36	59	59	1015	1053	0.3
Cuarenteño	36	36	59	62	1462	491	1.1
CNF 480	40	39	73	71	2730	951	1.1
Canario 107	35	34	64	61	938	696	0.3
FM RMC	36	36	70	70	1380	775	0.7
Icta Ostúa	43	44	73	77	2175	687	1.0
DOR 482	43	43	74	72	1819	882	0.8
Anova	*	*	*	*	*	**	*
LSD (5%)	1.6	2.0	3.7	5.4	965	397	0.5

[z] Total moisture provided by sprinkler irrigation. Last irrigation on stress plots at 14 days after planting.

[y] DSI= (1-(yield stress/yield control))/(1-(average yield stress/average yield control))

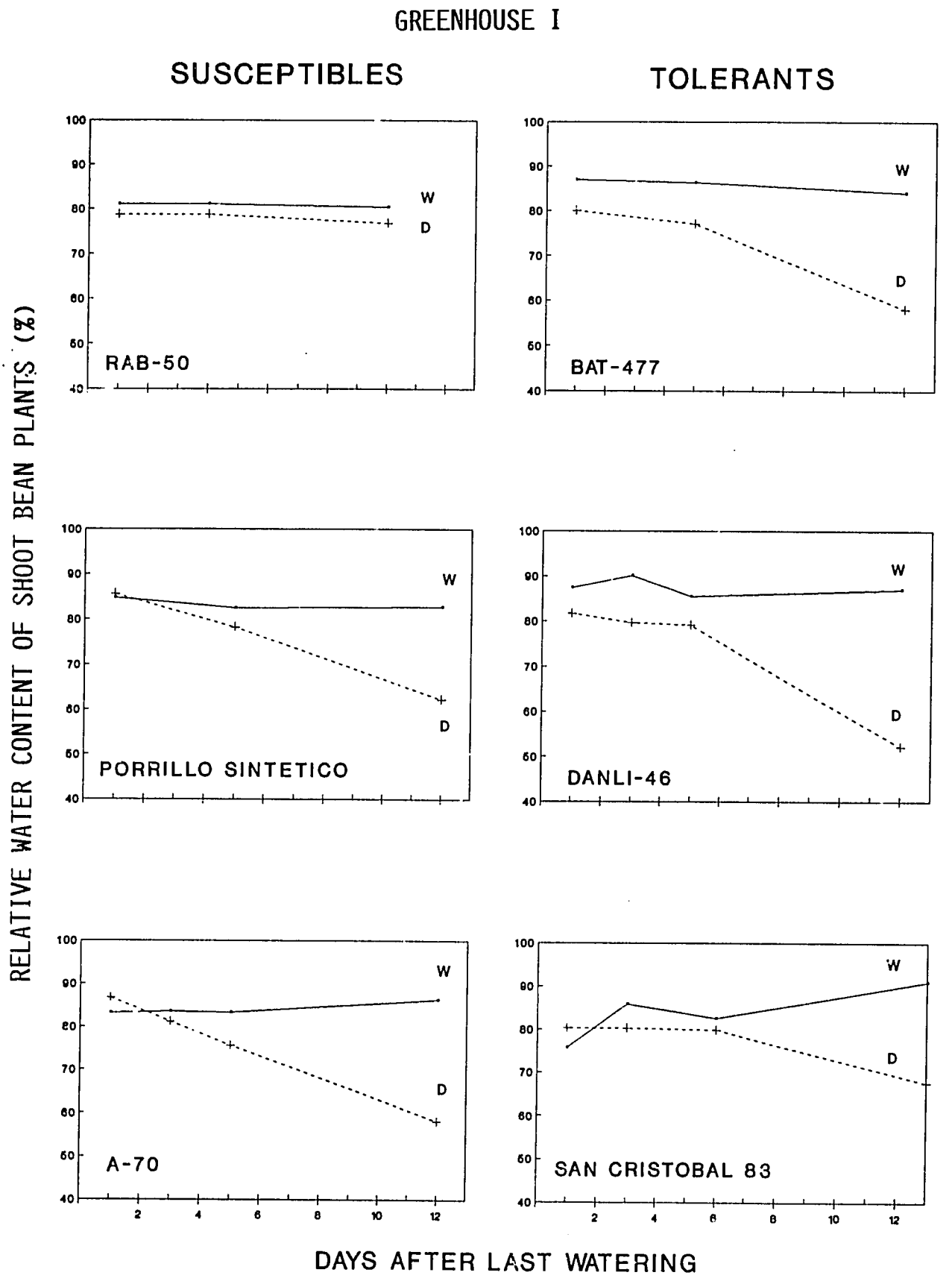
* and ** Significant at P< .01 and .05, respectively.

B. Group 2. Three experiments were carried out in a greenhouse and one in the field. The first experiment (Figures 1-8, Greenhouse I) was established in the greenhouse, 6 Kg of sterilized compost soil was used in each pot and one plant per pot. Plants were maintained under well water conditions until flowering, when water was withheld from a group of plants. Thereafter physiological and metabolic measurements were determined. Sampling and physiological measurements were done between 1200 and 1330 h. After the stress period plants were watered again and maintained in well watered conditions until full maturity and seed harvest.

The physiological parameters were determined by conventional procedures: Water Potential was determined with the Schollander pump (Corvallis, Oregon). Solute Potential was determined by psychrometic techniques (Wescor Inc, USA) and Turgor Potential was calculated from the standard equation. Relative Water Content was measured from discs of the youngest leaf. Proline was measured following the procedure described by Bates (1973) on leaves from the 6th or 7th nodes. Potassium was determined using an atomic absorption photometer. Carbohydrates were determined in leaves from the 5th or 6th nodes by the Nelson Somogi colorimetric method. Two additional experiments were run in the greenhouse (Figures 9-24, Greenhouse II and III). However plants in these experiments were placed in 20 L pots to allow root development and adequate water shortage. The material for field experiments (Figures 25-32, Field Experiment) was planted in rows following a completely random design pattern using standard fertilization recommendations (80-40-00). Seedlings were transplanted to the field to insure homogenous population.

Results (Figures 1-32) showed that there was no clear evidence of osmotic adjustment in any of the cultivars despite the fact that results were from four different experimental conditions (differences in water potential and relative water content of the plants under stress, indicated presence of stress). Furthermore, small and variable differences were observed in carbohydrates or potassium accumulation among the genotypes in response to drought treatments. Proline accumulation was the only variable that gave significant differences. However, the differences were present only when the drought was given in a short period. The yield results in any of the experiments showed no clear differences among cultivars. This is a surprise since it was expected that the drought tolerant material could yield better than the susceptible genotypes. The explanation may be due to the fact that experiments were done mostly in pots and because genotypes were developed in a warm and humid climate at low altitudes but the conditions at which experiments were conducted were very different (lack of environmental adaptation).

Figure 1


GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
RELATIVE WATER CONTENT OF SHOOT BEAN PLANTS (%)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
DAYS AFTER LAST WATERING

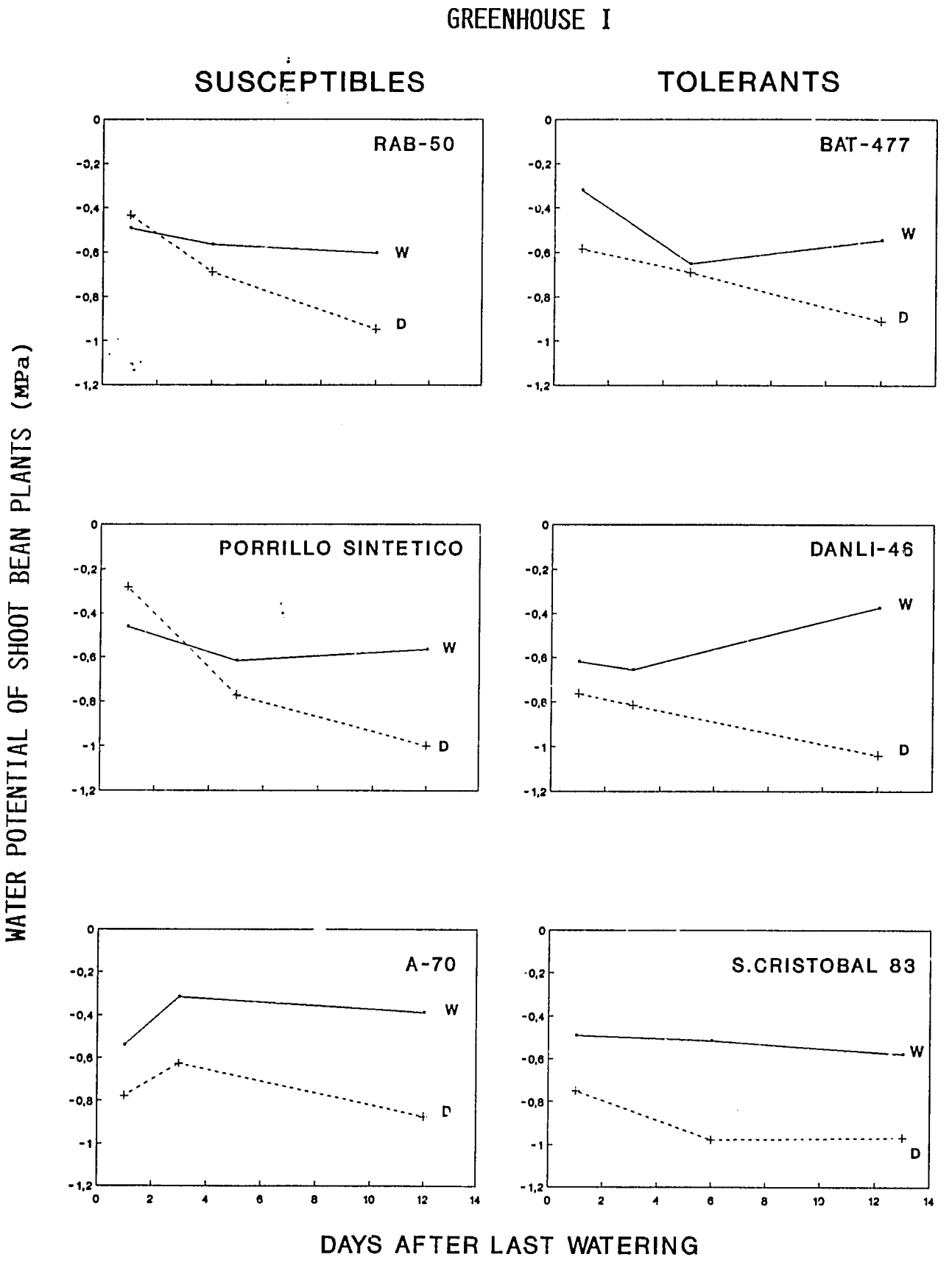

GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
WATER POTENTIAL OF SHOOT BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING

Figure 3

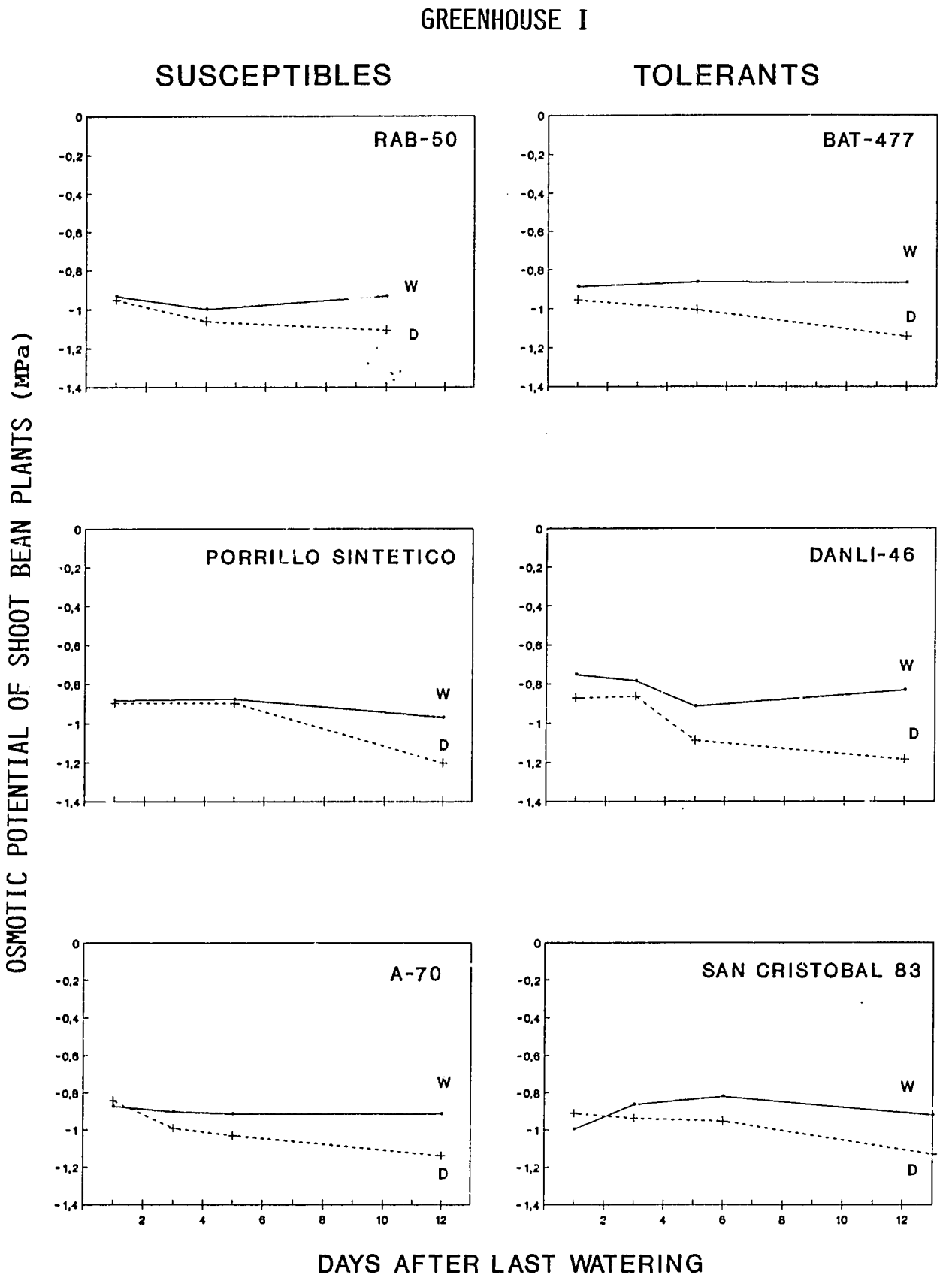
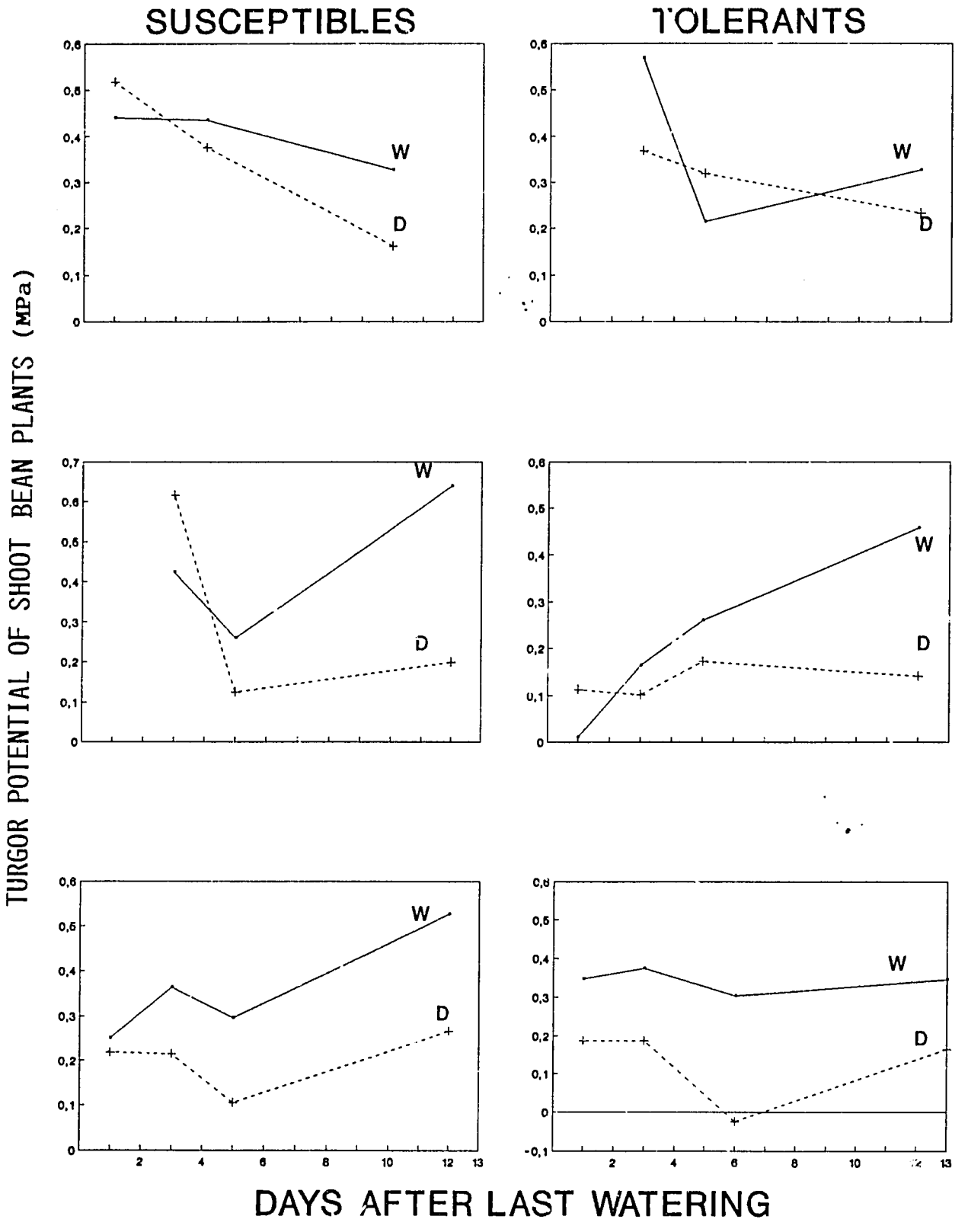
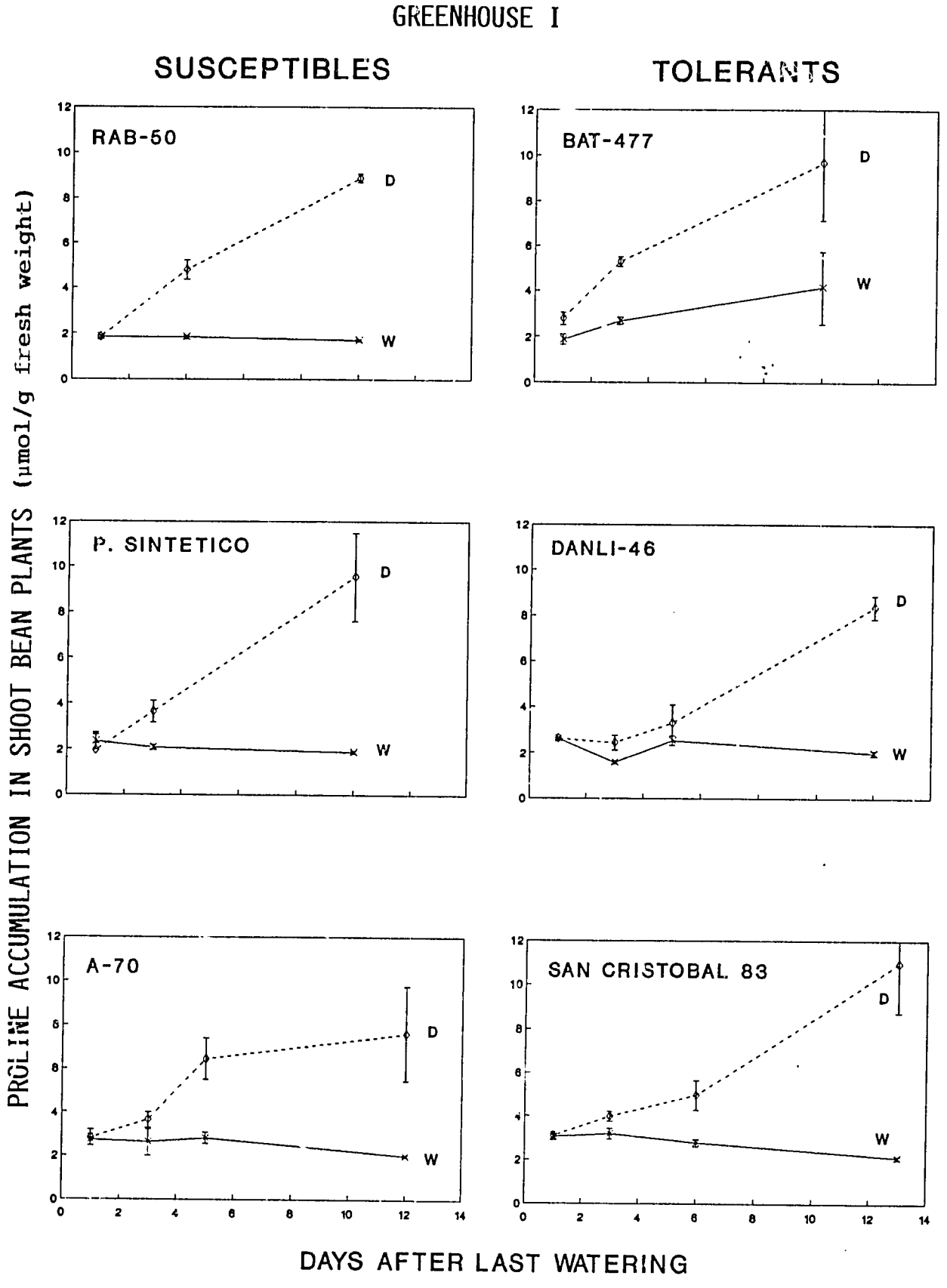
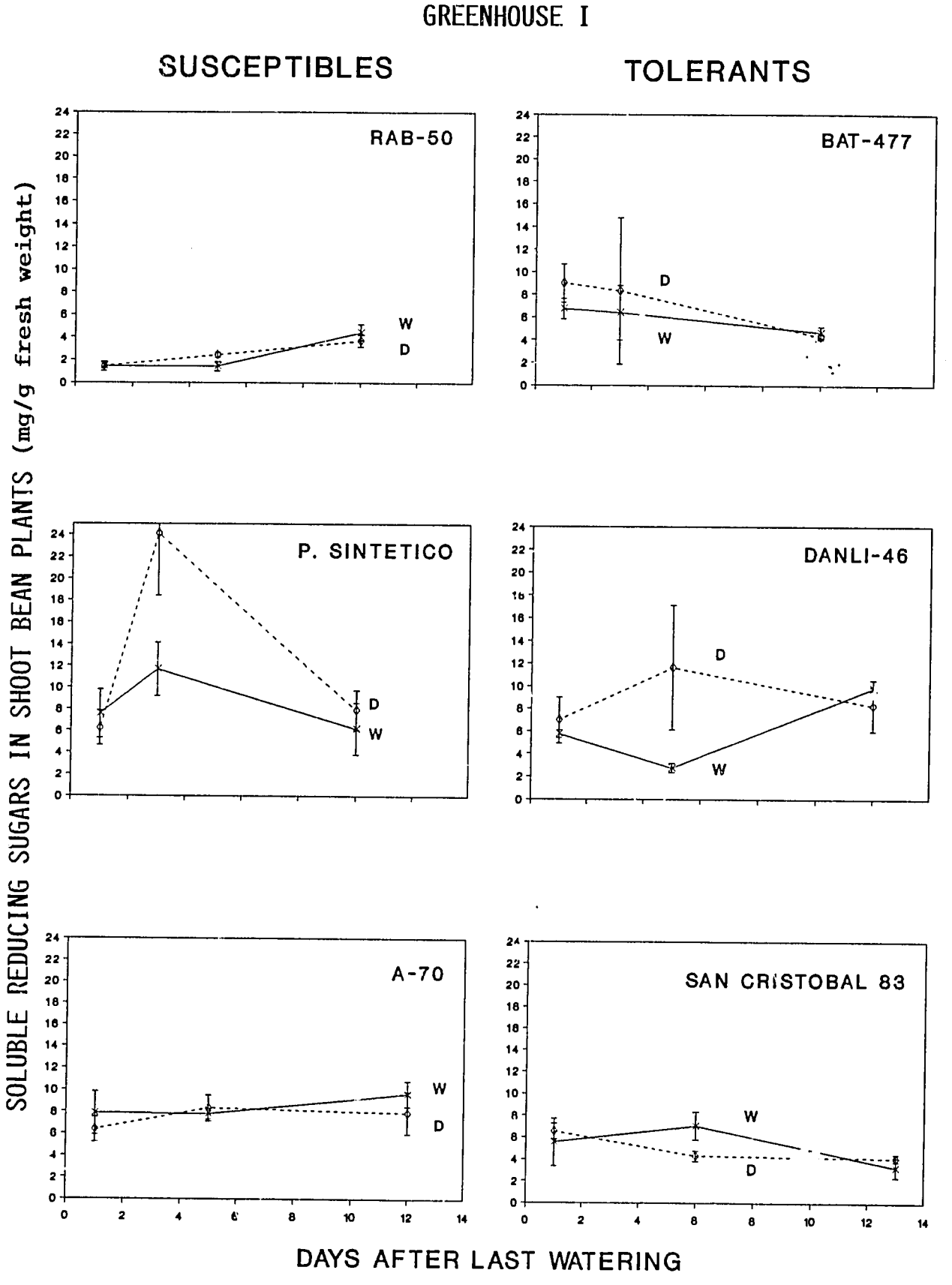

GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
OSMOTIC POTENTIAL OF SHOOT BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING

Figure 4

GREENHOUSE I




GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
P. SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
PROLINE ACCUMULATION IN SHOOT BEAN PLANTS (µmol/g fresh weight)
DAYS AFTER LAST WATERING


GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
P. SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
SOLUBLE REDUCING SUGARS IN SHOOT BEAN PLANTS (mg/g fresh weight)
DAYS AFTER LAST WATERING

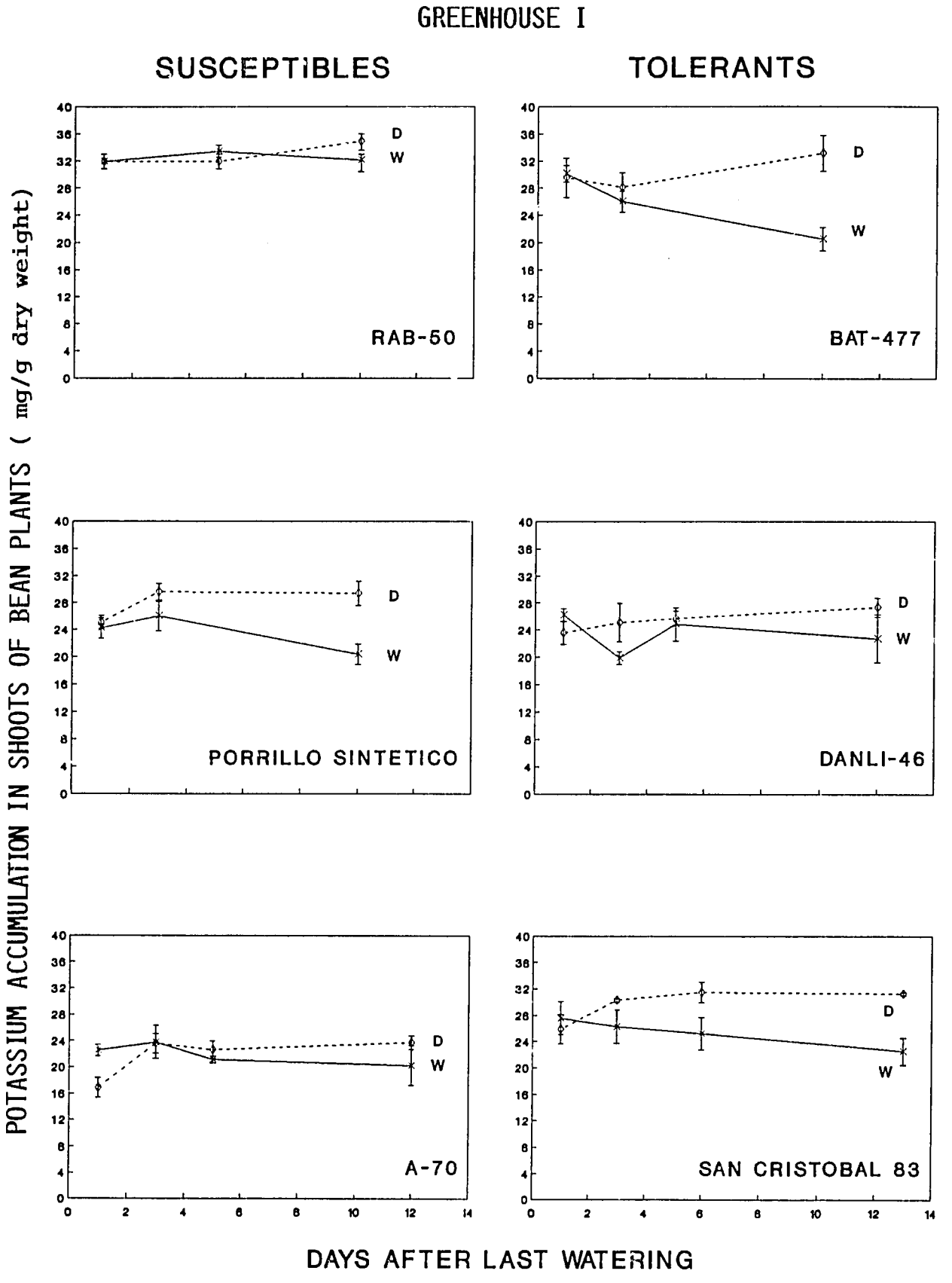

GREENHOUSE I
SUSCEPTIBLES
TOLERANTS
POTASSIUM ACCUMULATION IN SHOOTS OF BEAN PLANTS (mg/g dry weight)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
DAYS AFTER LAST WATERING

Figure 8

GREENHOUSE I

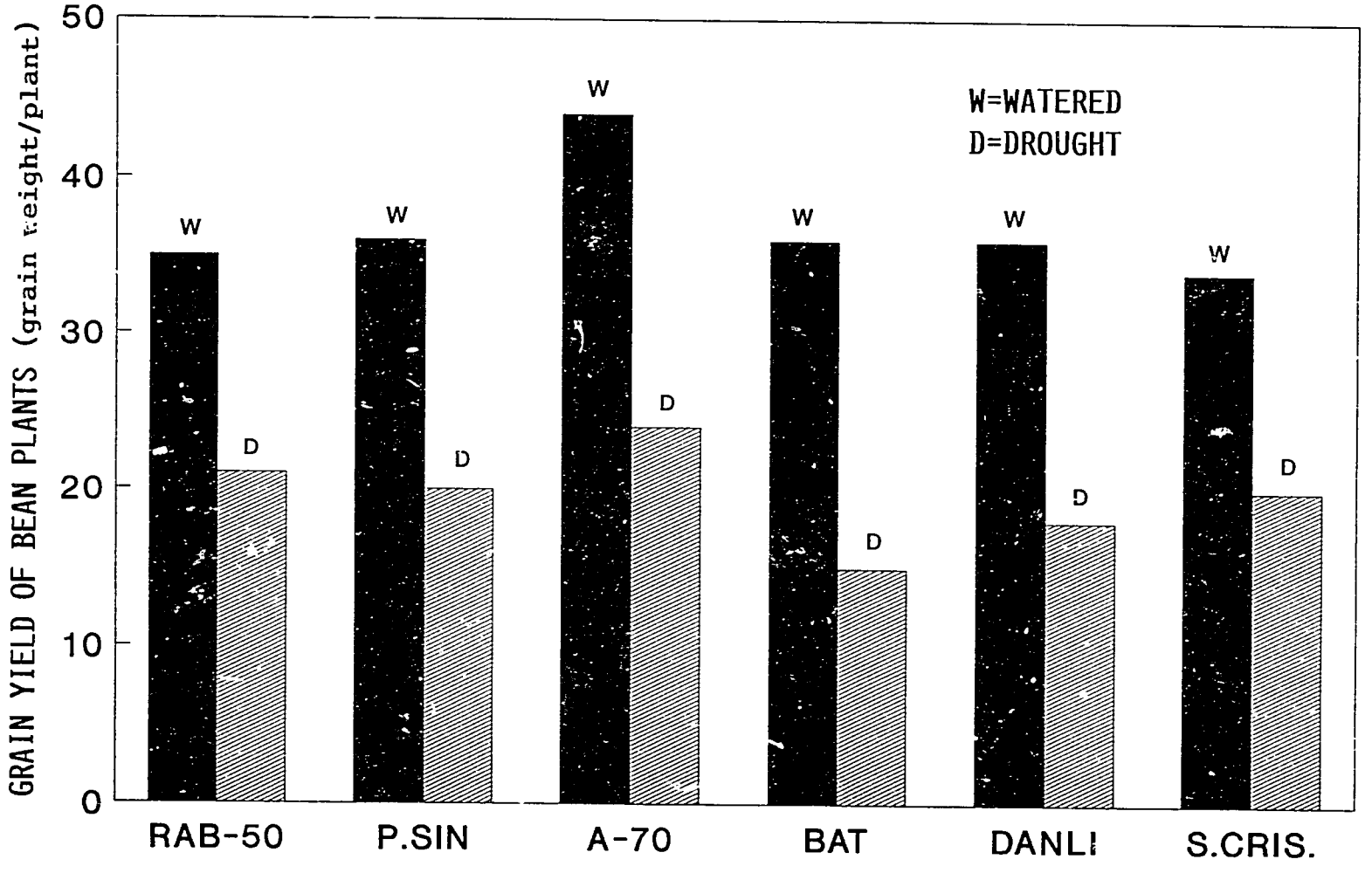


Figure 9

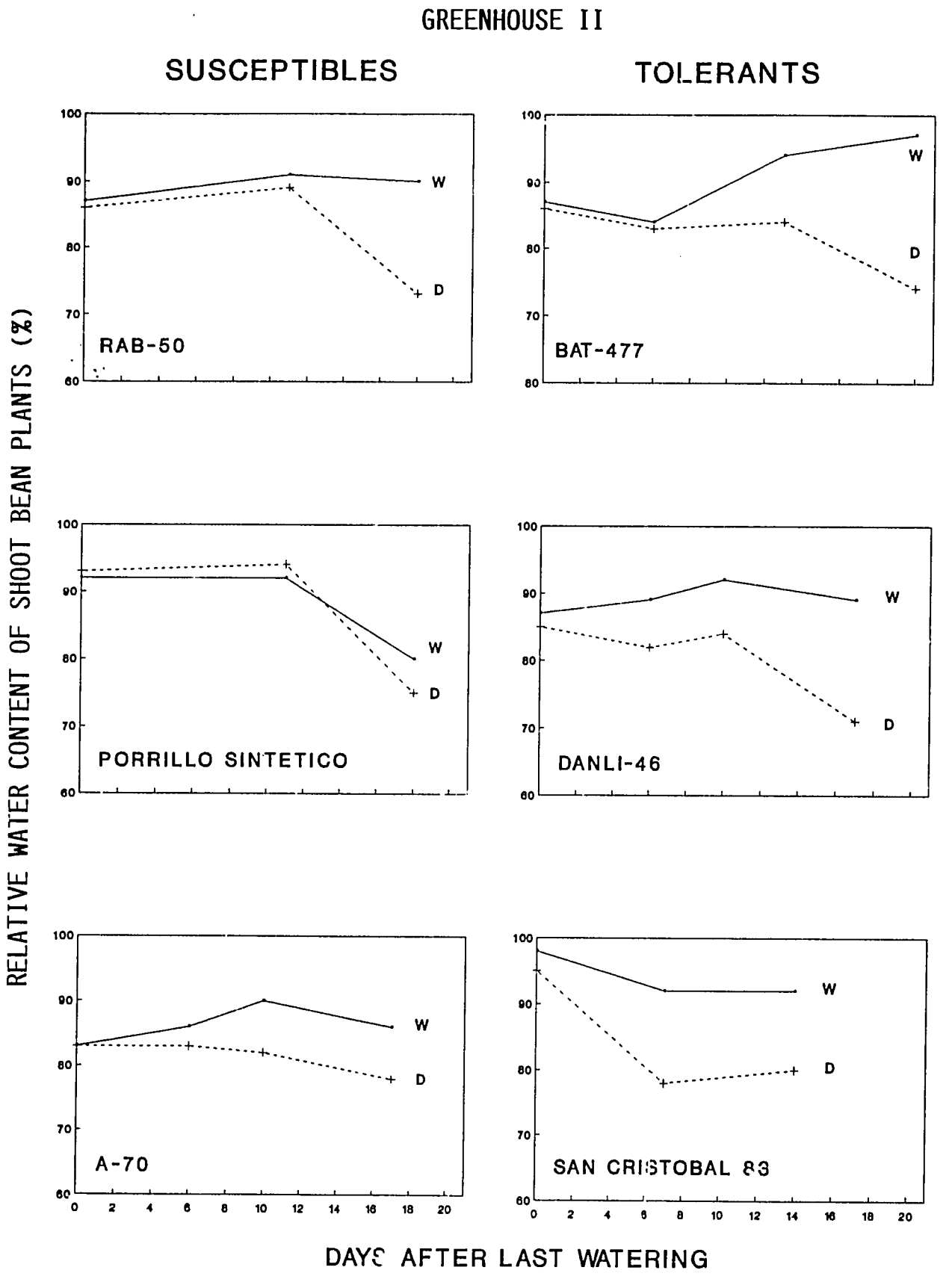
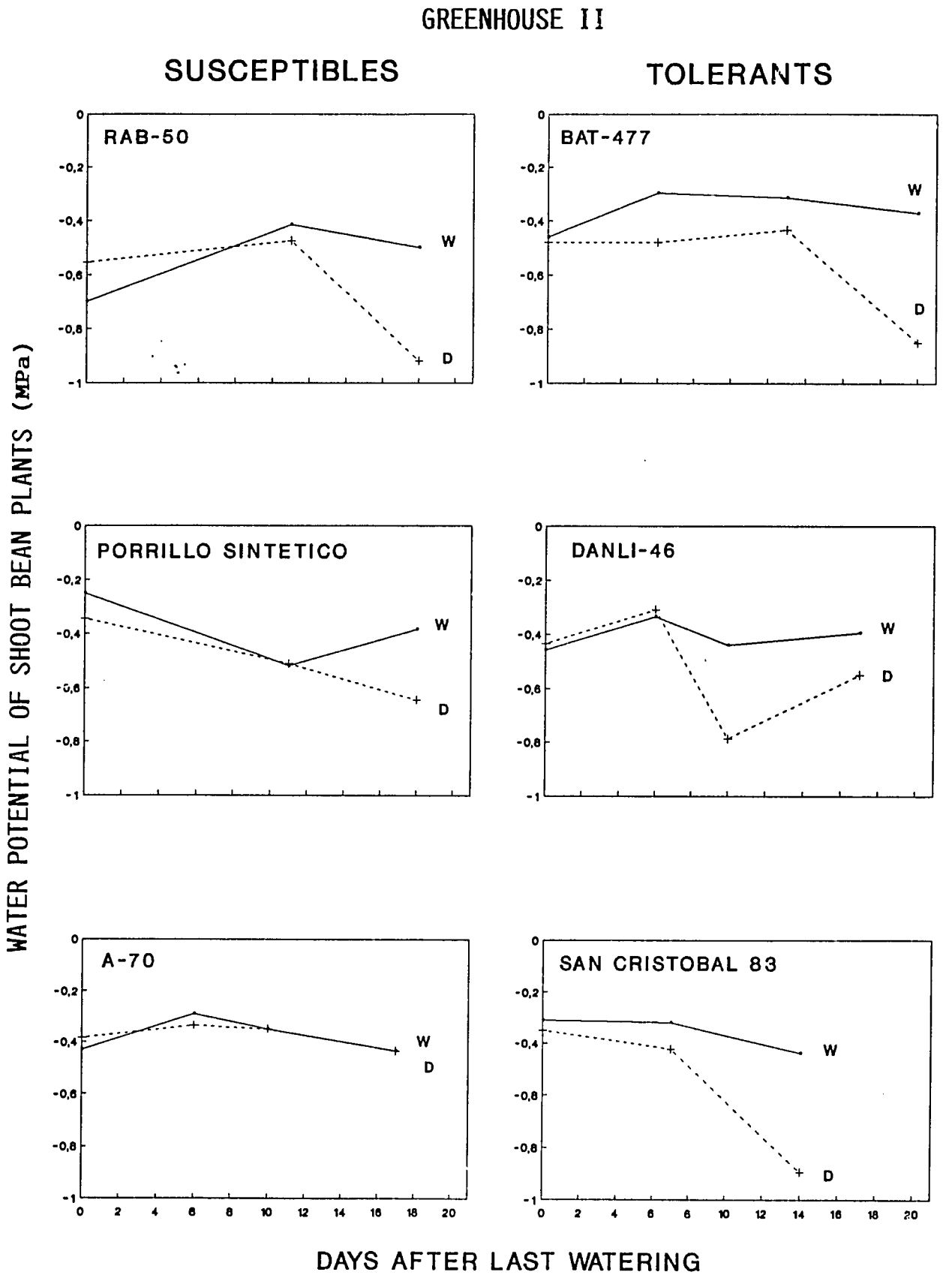
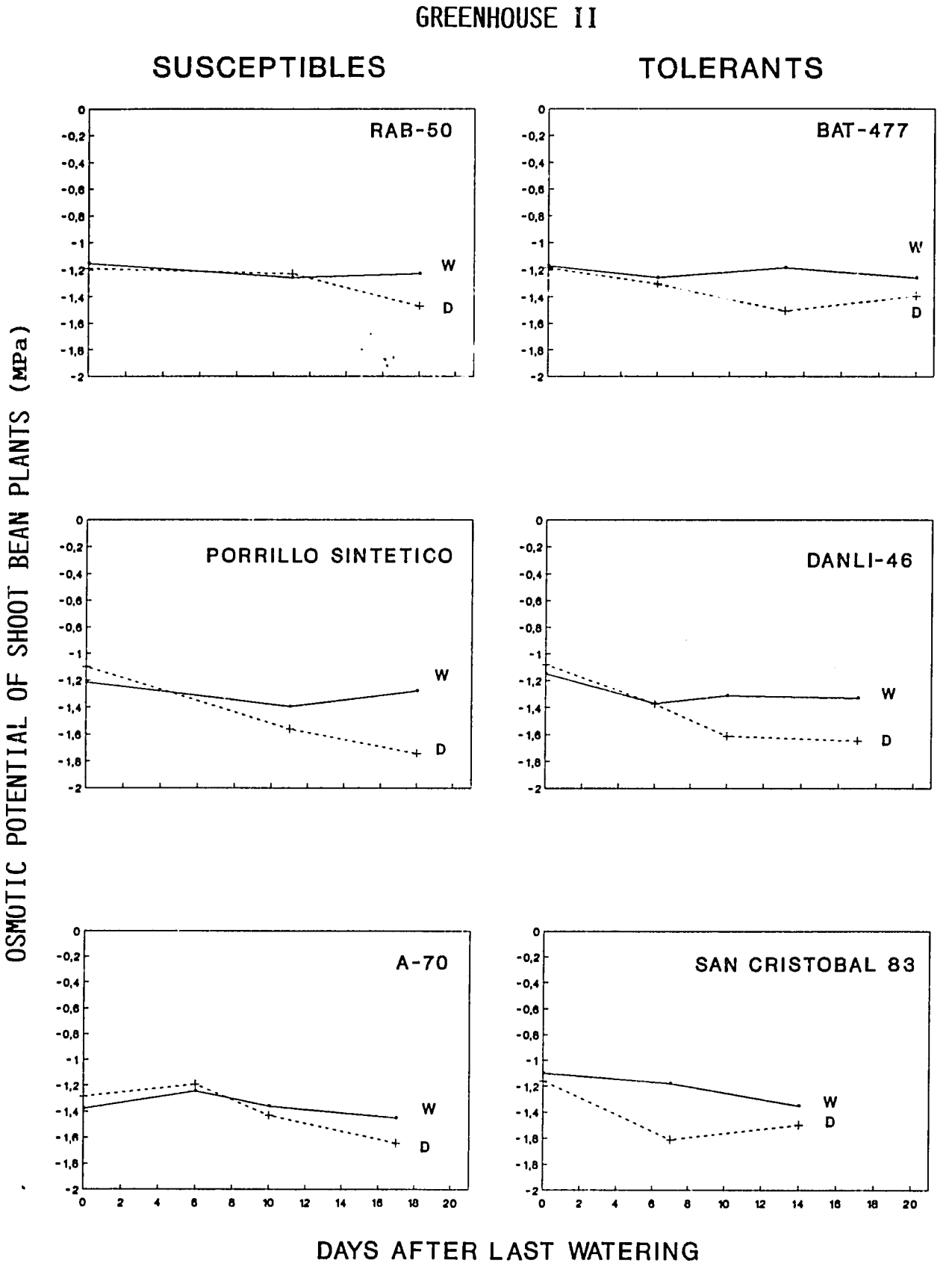
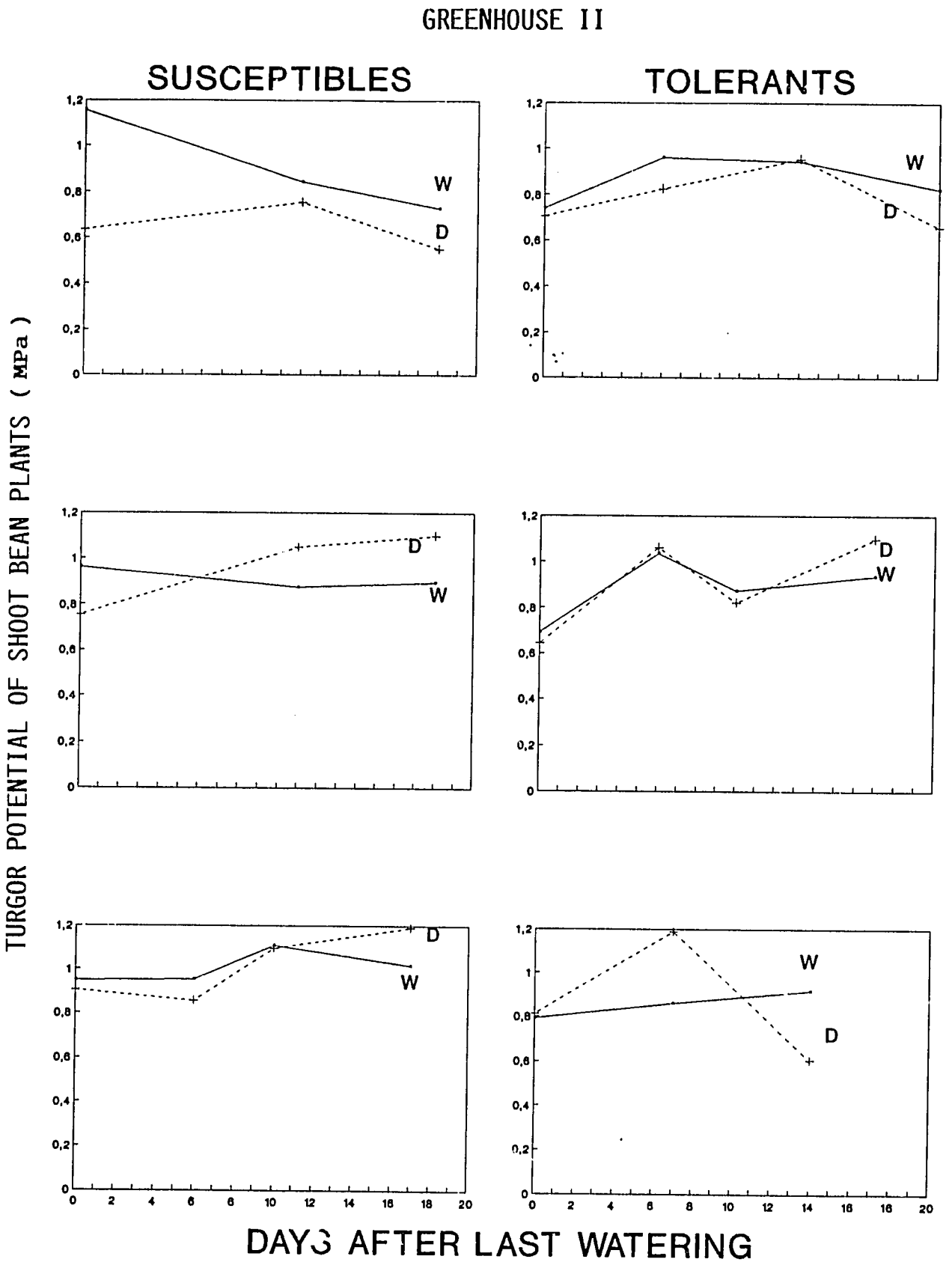
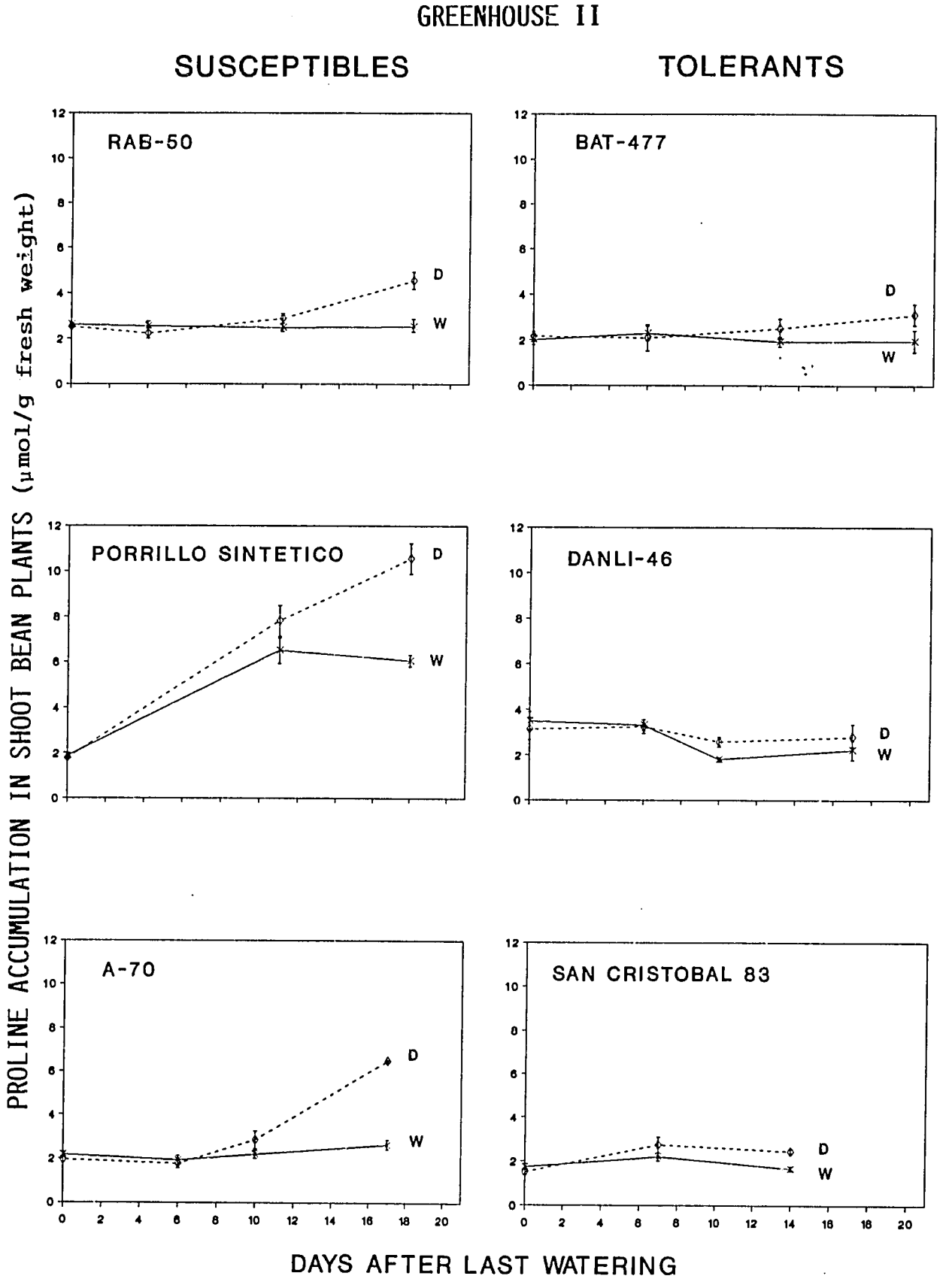

GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
RELATIVE WATER CONTENT OF SHOOT BEAN PLANTS (%)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
DAYS AFTER LAST WATERING

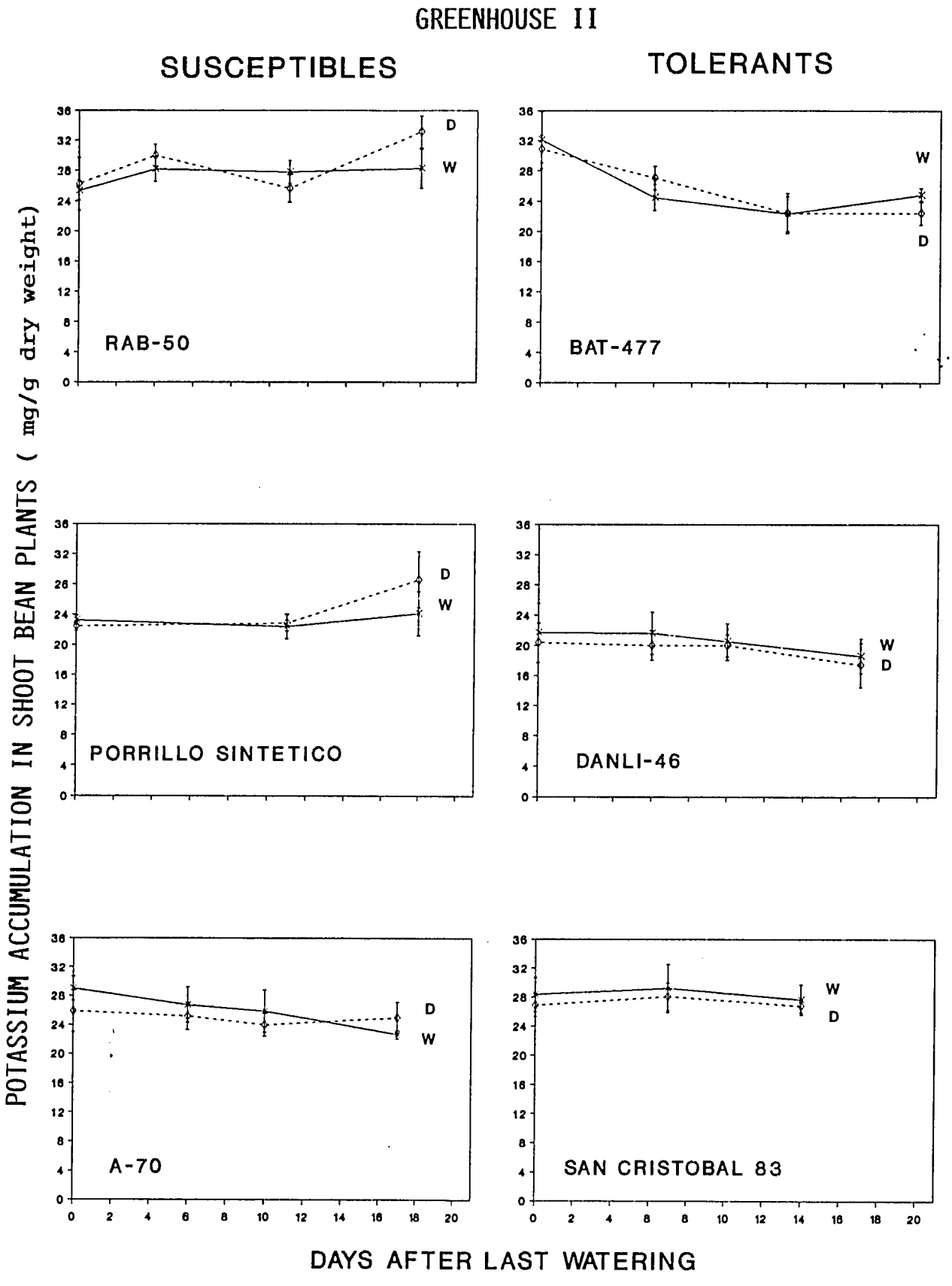
Figure 10


GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
WATER POTENTIAL OF SHOOT BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING


GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
OSMOTIC POTENTIAL OF SHOOT BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING


GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
TURGOR POTENTIAL OF SHOOT BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING
W
D


GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
PROLINE ACCUMULATION IN SHOOT BEAN PLANTS (µmol/g fresh weight)
DAYS AFTER LAST WATERING


GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
POTASSIUM ACCUMULATION IN SHOOT BEAN PLANTS (mg/g dry weight)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
DAYS AFTER LAST WATERING

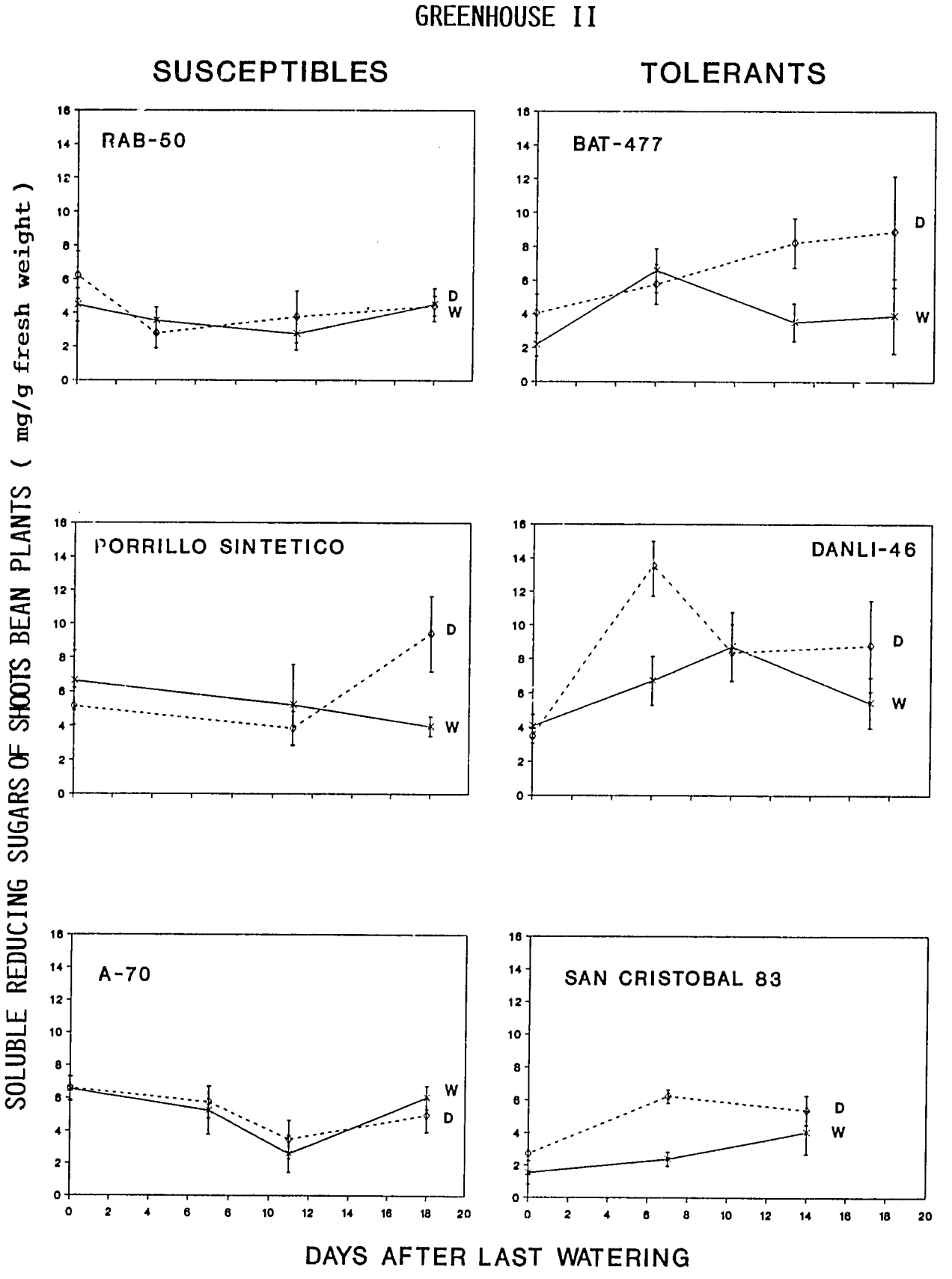
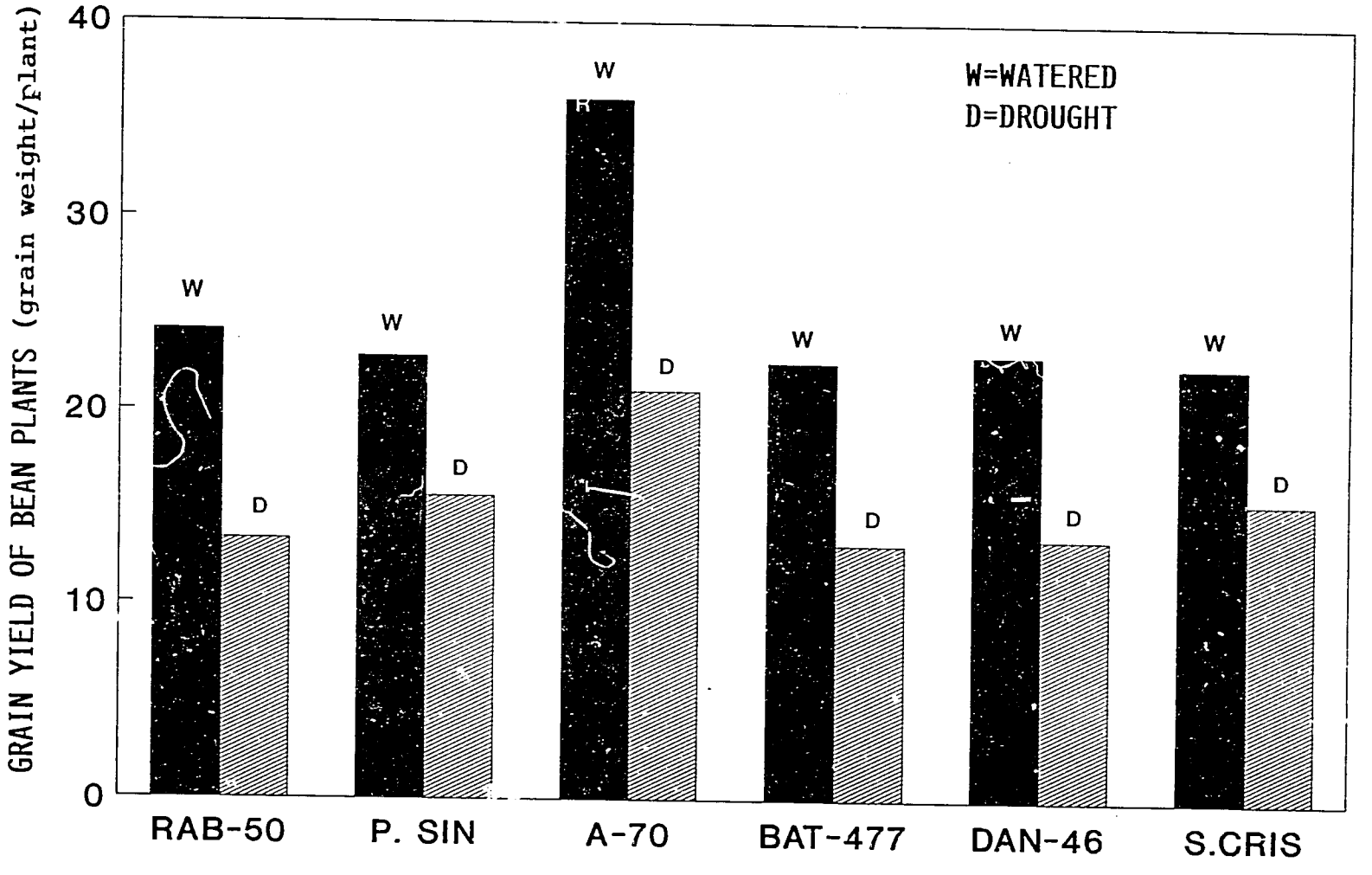
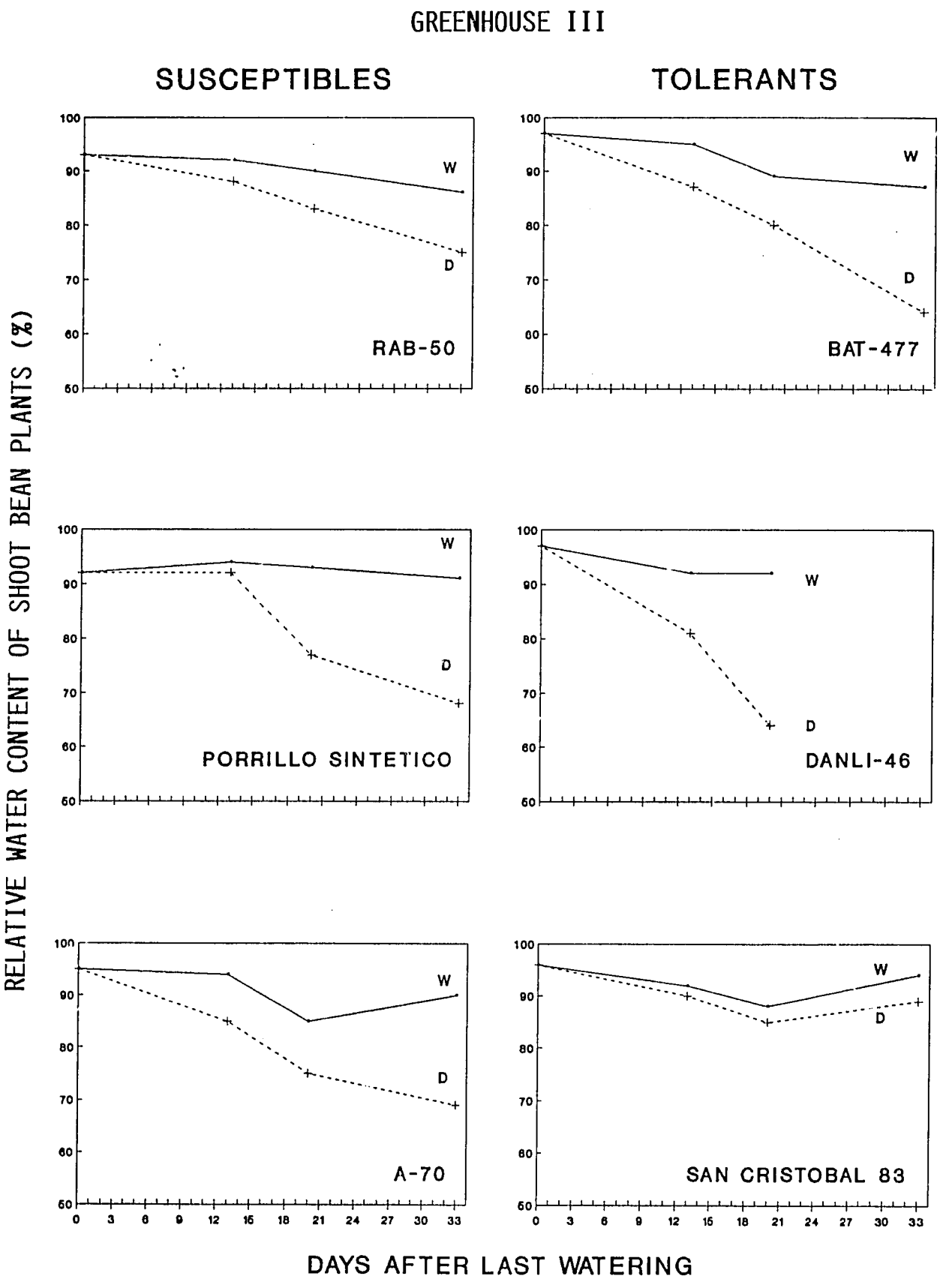

GREENHOUSE II
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
SOLUBLE REDUCING SUGARS OF SHOOTS BEAN PLANTS (mg/g fresh weight)
DAYS AFTER LAST WATERING

Figure 16

GREENHOUSE II




GREENHOUSE III
SUSCEPTIBLES
TOLERANTS
RELATIVE WATER CONTENT OF SHOOT BEAN PLANTS (%)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
DAYS AFTER LAST WATERING

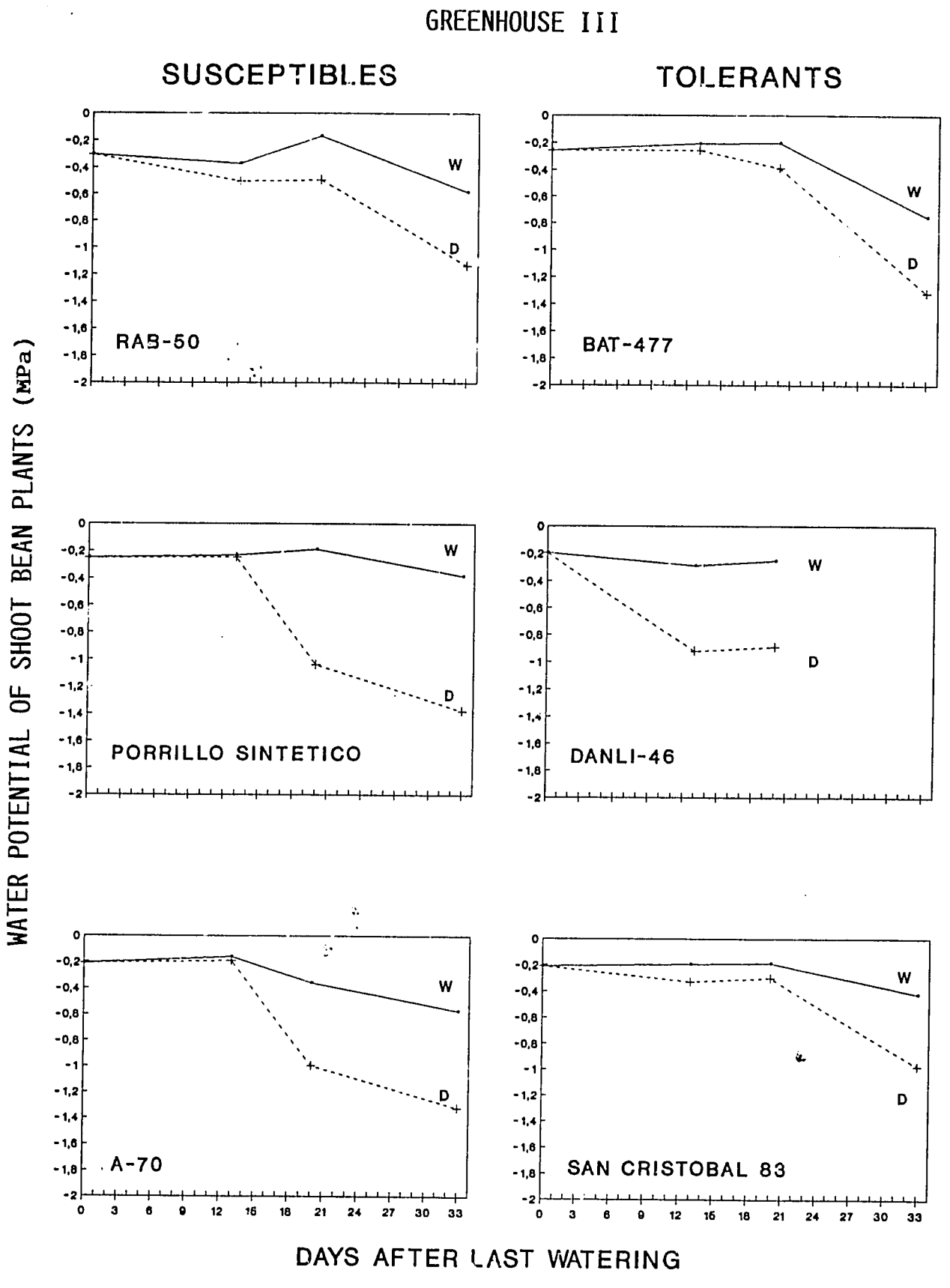
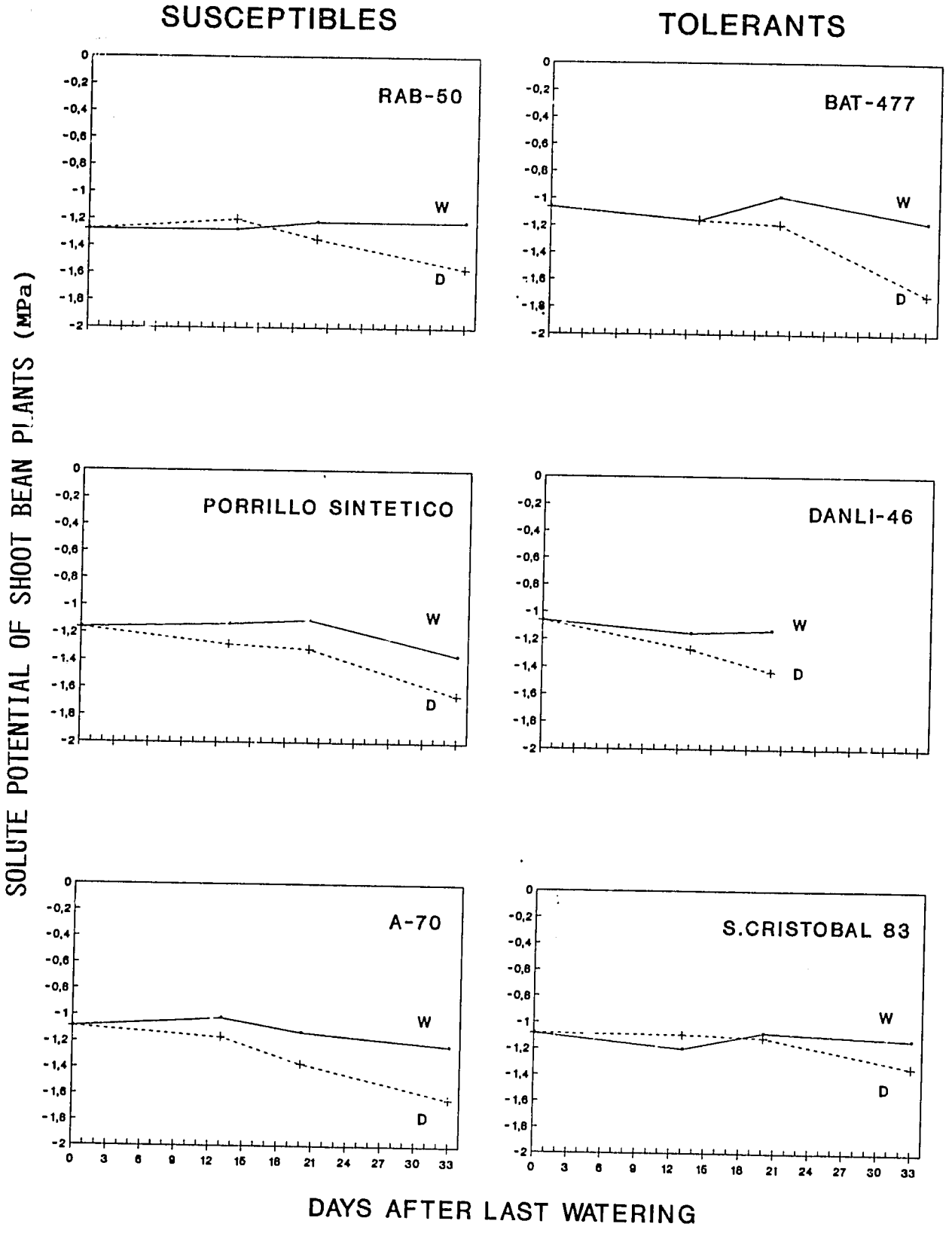
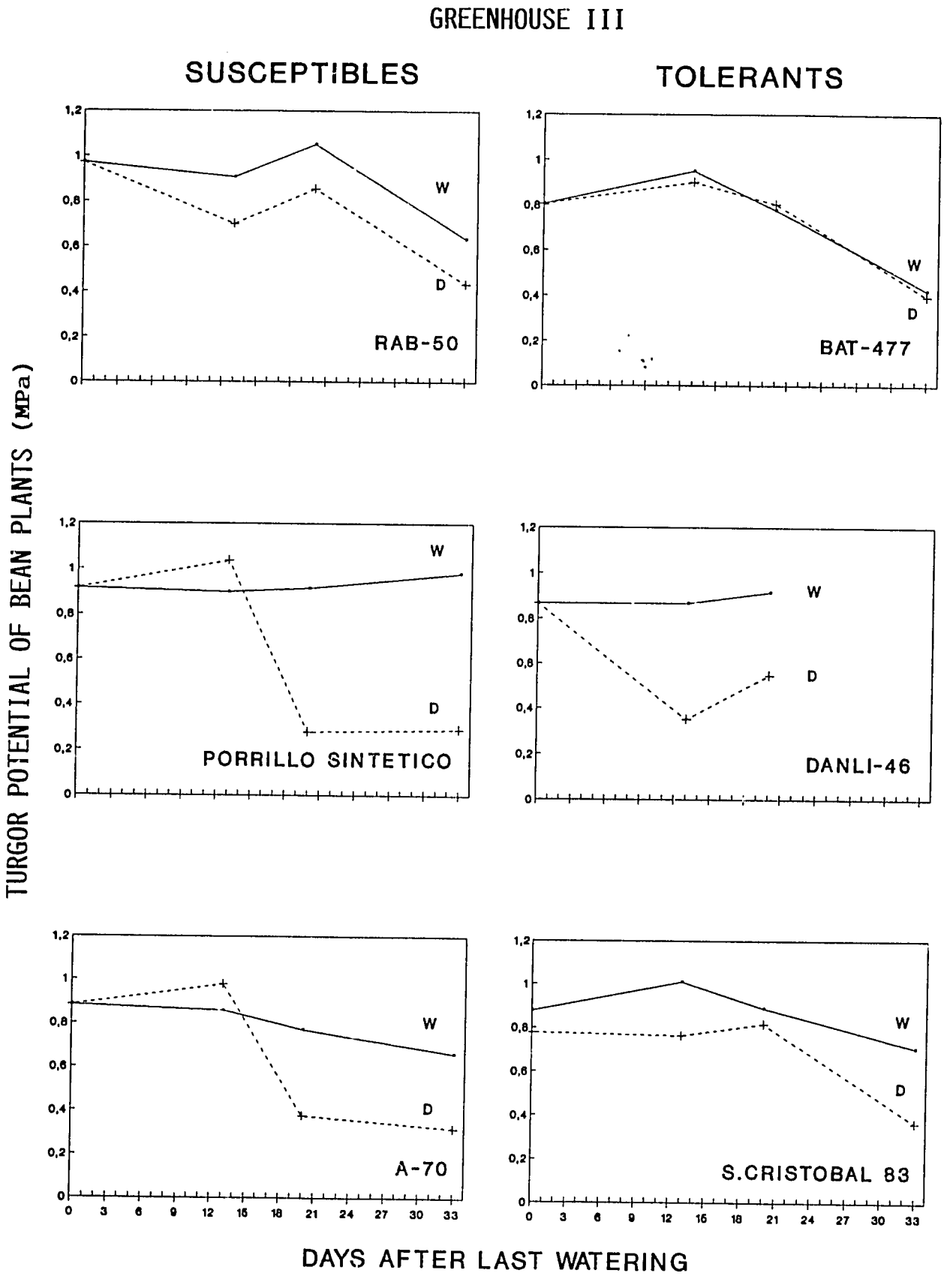

GREENHOUSE III
SUSCEPTIBLES
TOLERANTS
WATER POTENTIAL OF SHOOT BEAN PLANTS (MPa)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
W
D
0
-0,2
-0,4
-0,6
-0,8
-1
-1,2
-1,4
-1,6
-1,8
-2
0 3 6 9 12 15 18 21 24 27 30 33
DAYS AFTER LAST WATERING

Figure 19

GREENHOUSE III




GREENHOUSE III
SUSCEPTIBLES
TOLERANTS
TURGOR POTENTIAL OF BEAN PLANTS (MPa)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
DAYS AFTER LAST WATERING

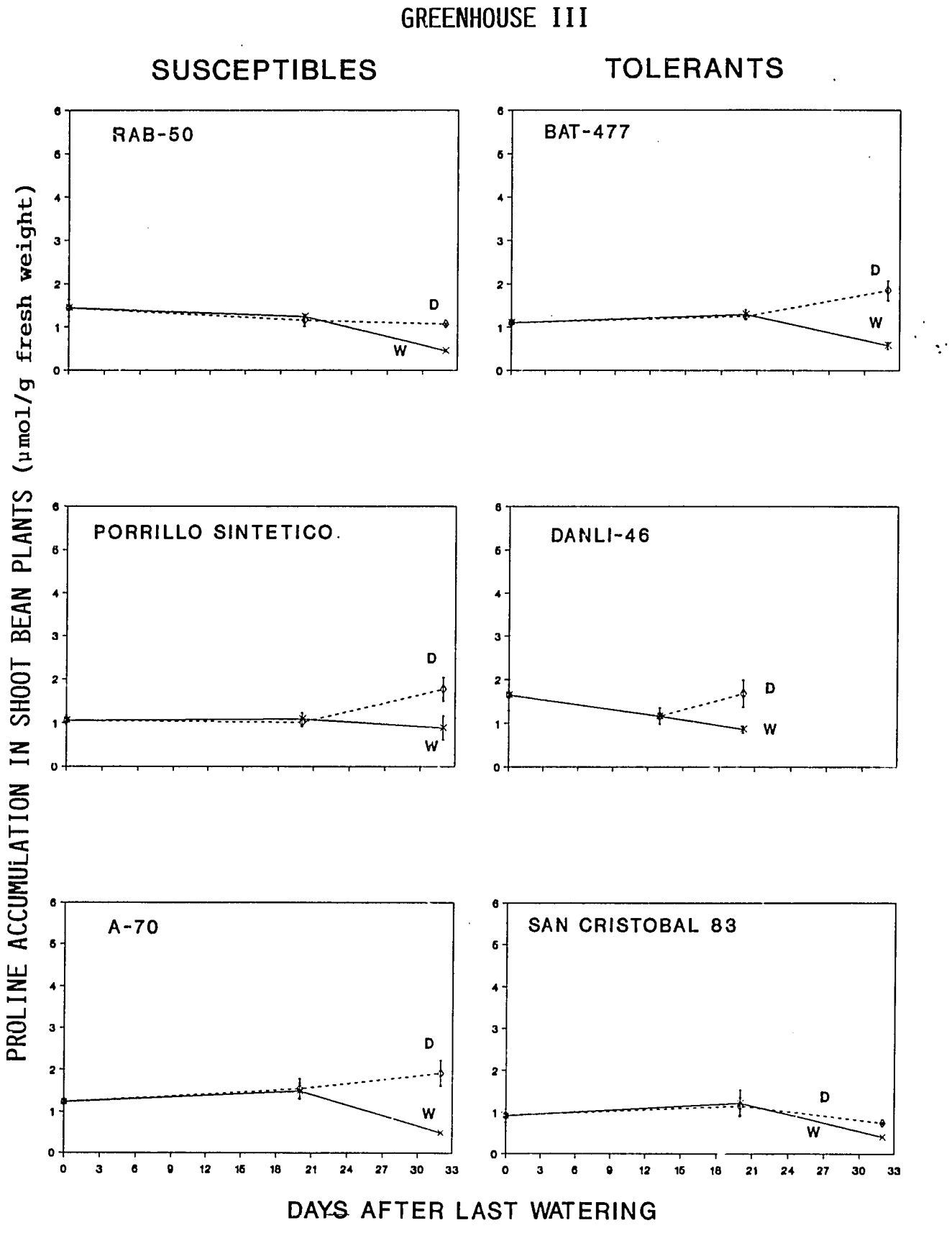

GREENHOUSE III
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
PROLINE ACCUMULATION IN SHOOT BEAN PLANTS (µmol/g fresh weight)
DAYS AFTER LAST WATERING

Figure 22

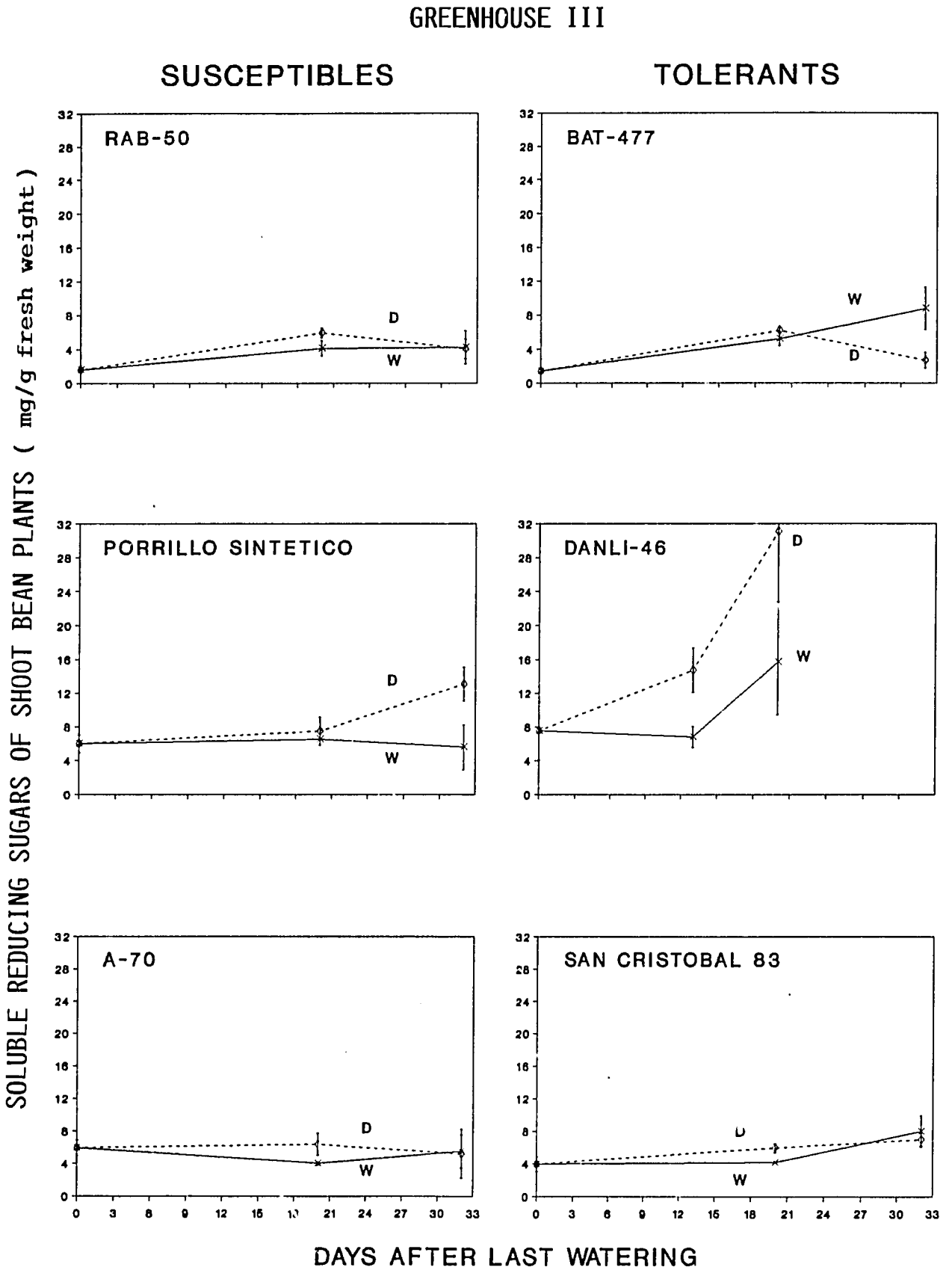
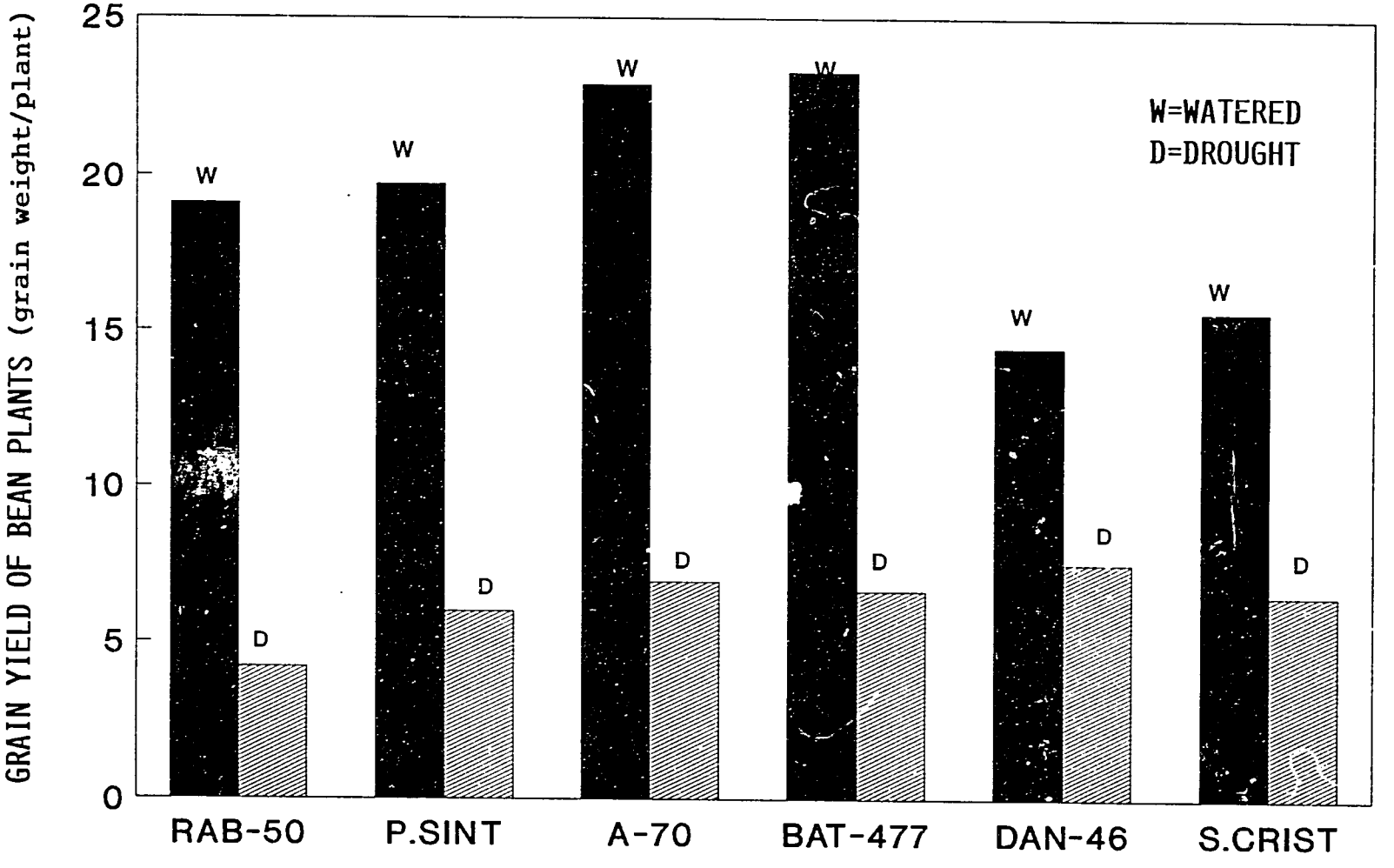

GREENHOUSE III
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
SOLUBLE REDUCING SUGARS OF SHOOT BEAN PLANTS (mg/g fresh weight)
DAYS AFTER LAST WATERING

Figure 23

GREENHOUSE III



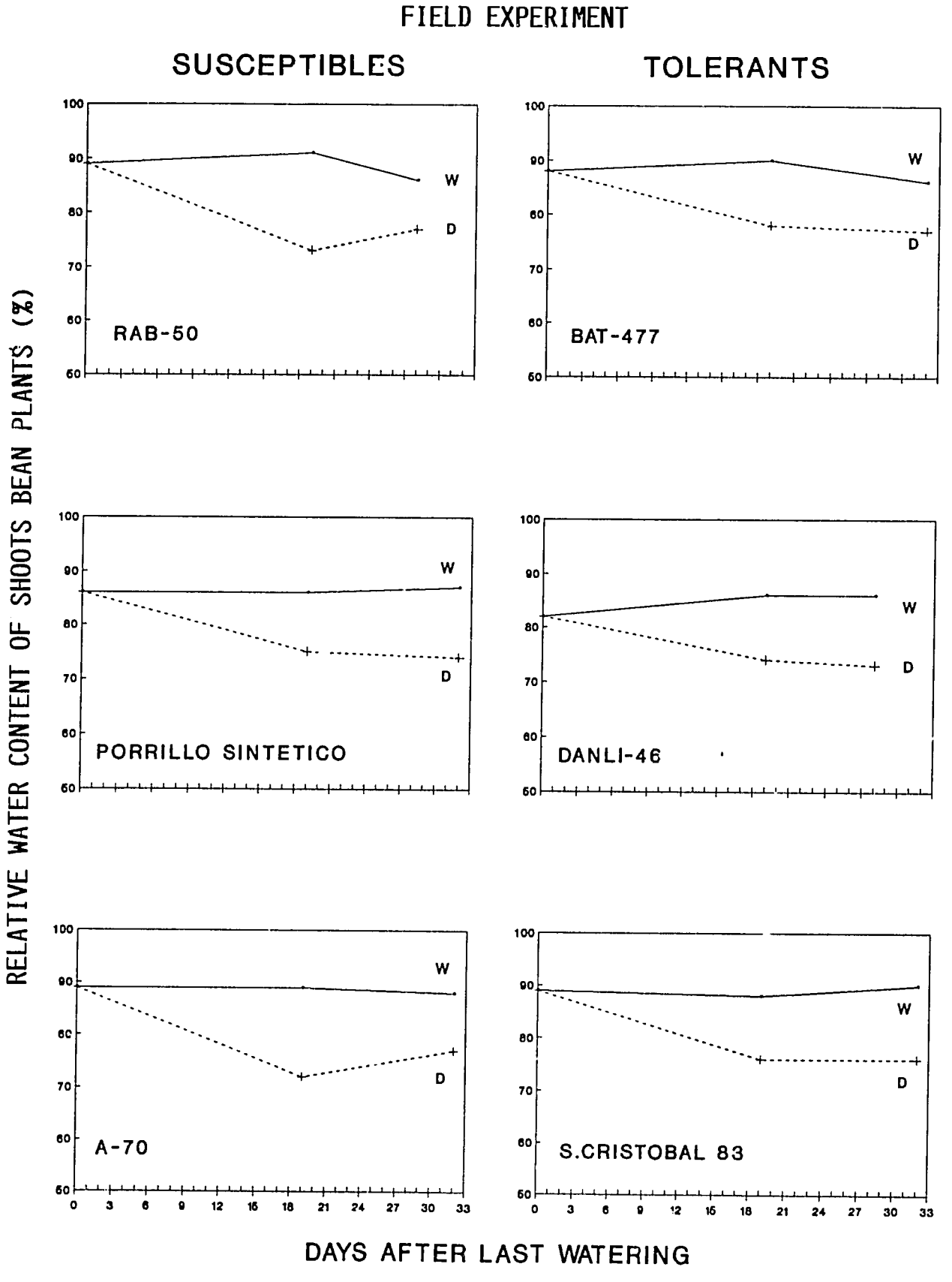
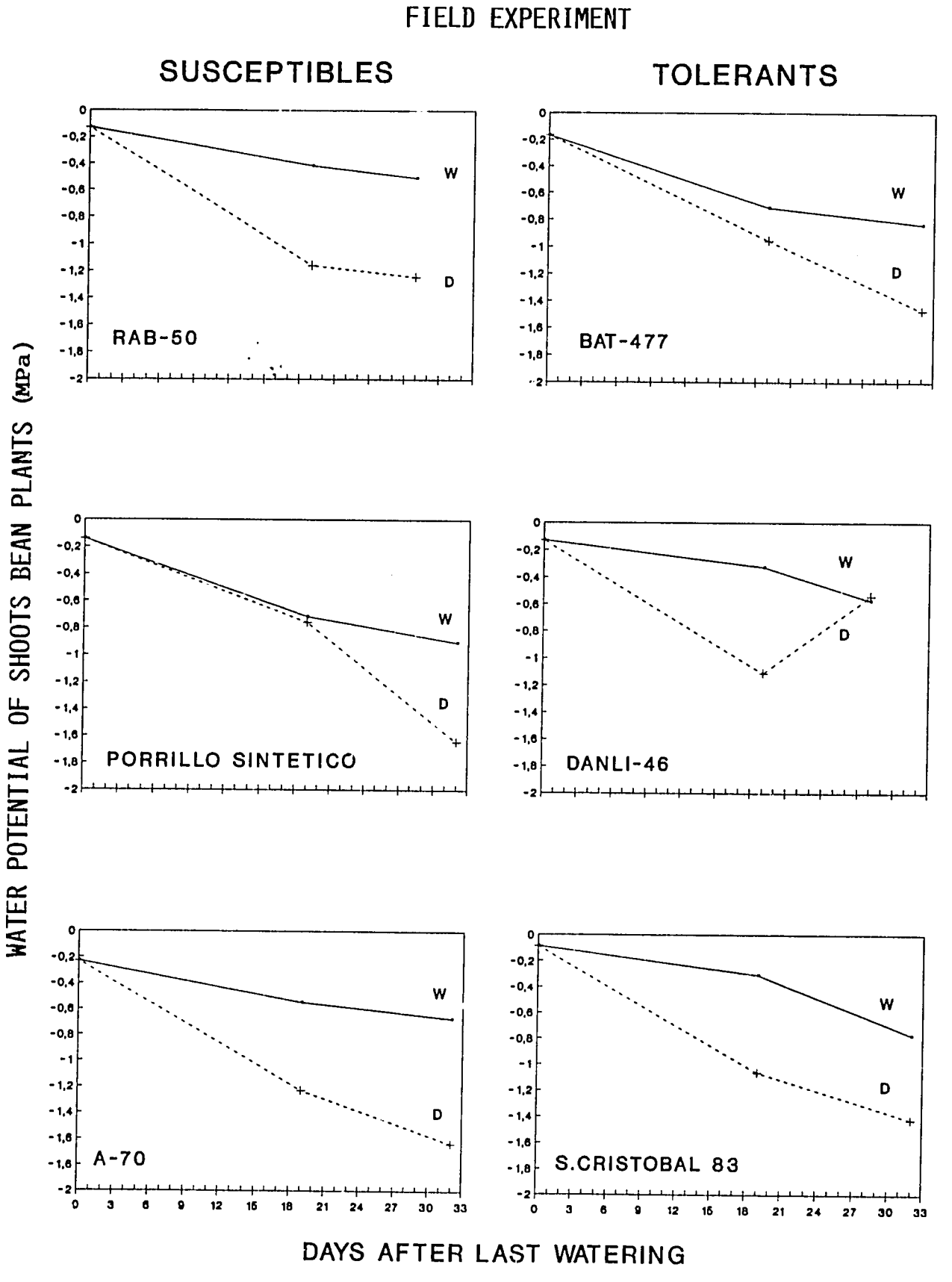
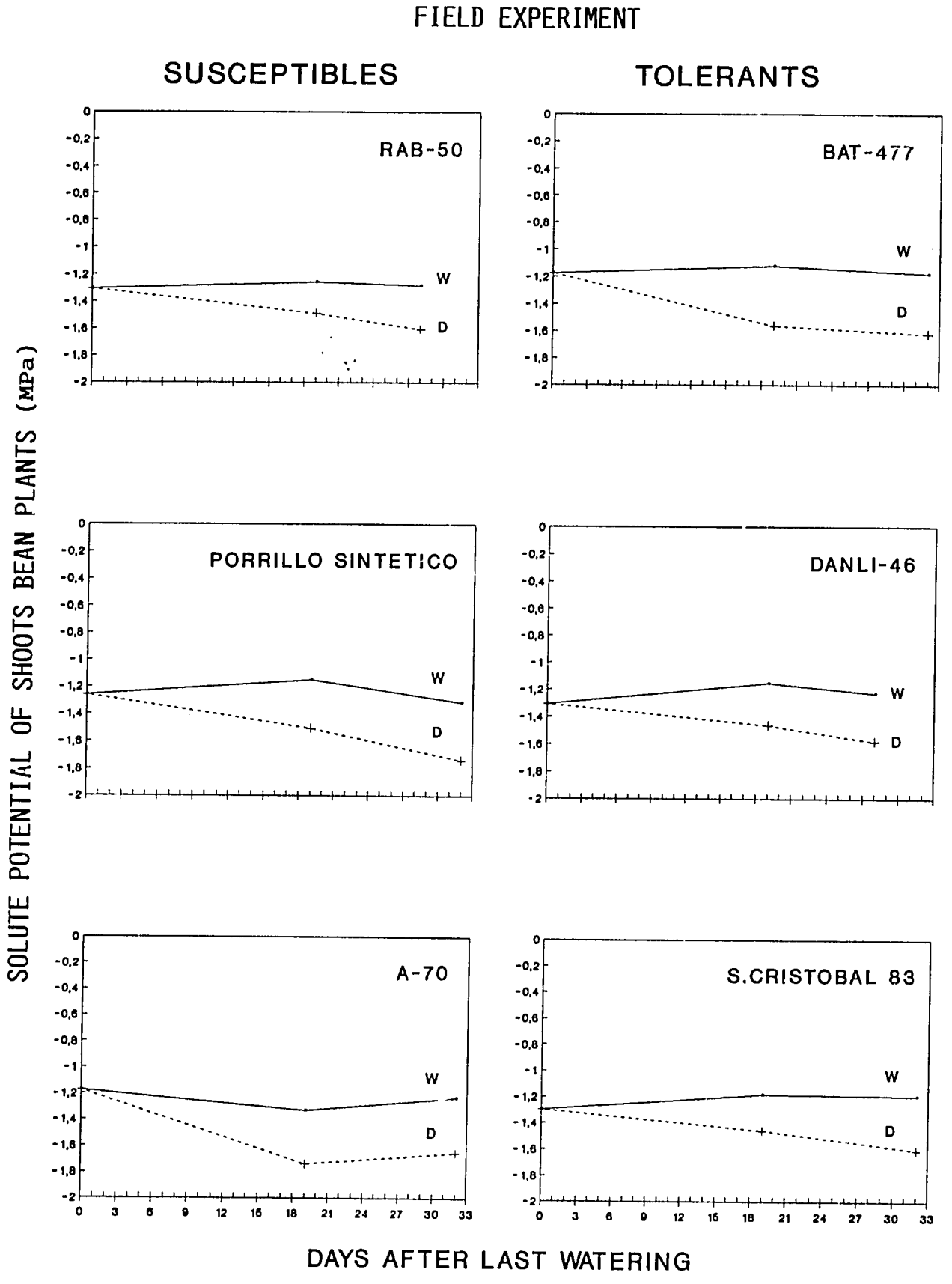

FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
RELATIVE WATER CONTENT OF SHOOTS BEAN PLANTS (%)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
100
90
80
70
60
50
0 3 6 9 12 15 18 21 24 27 30 33
DAYS AFTER LAST WATERING

Figure 25


FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
WATER POTENTIAL OF SHOOTS BEAN PLANTS (MPa)
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
DAYS AFTER LAST WATERING


FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
SOLUTE POTENTIAL OF SHOOTS BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING

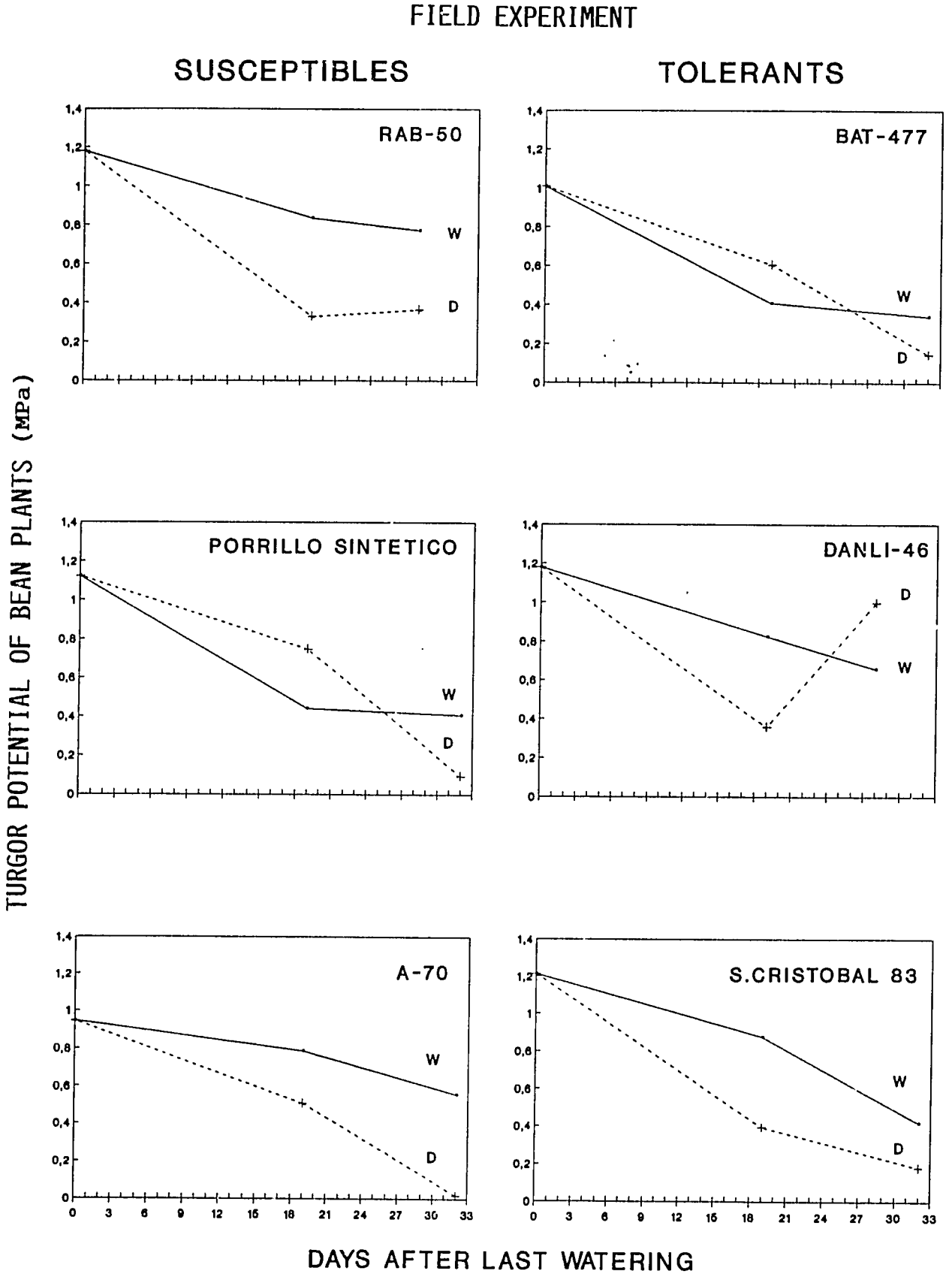
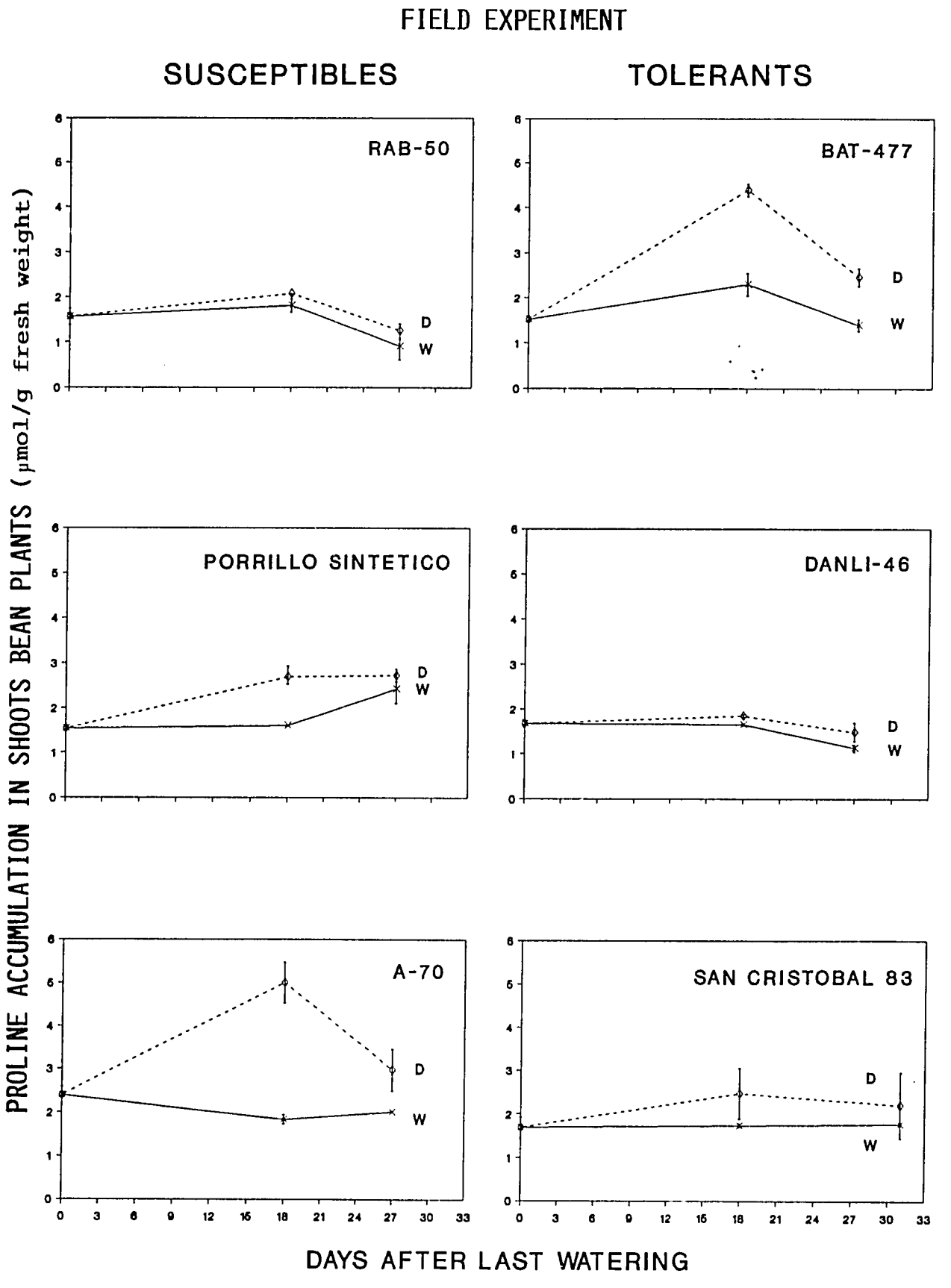

FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
S.CRISTOBAL 83
W
D
TURGOR POTENTIAL OF BEAN PLANTS (MPa)
DAYS AFTER LAST WATERING

Figure 28


FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
PROLINE ACCUMULATION IN SHOOTS BEAN PLANTS (µmol/g fresh weight)
DAYS AFTER LAST WATERING

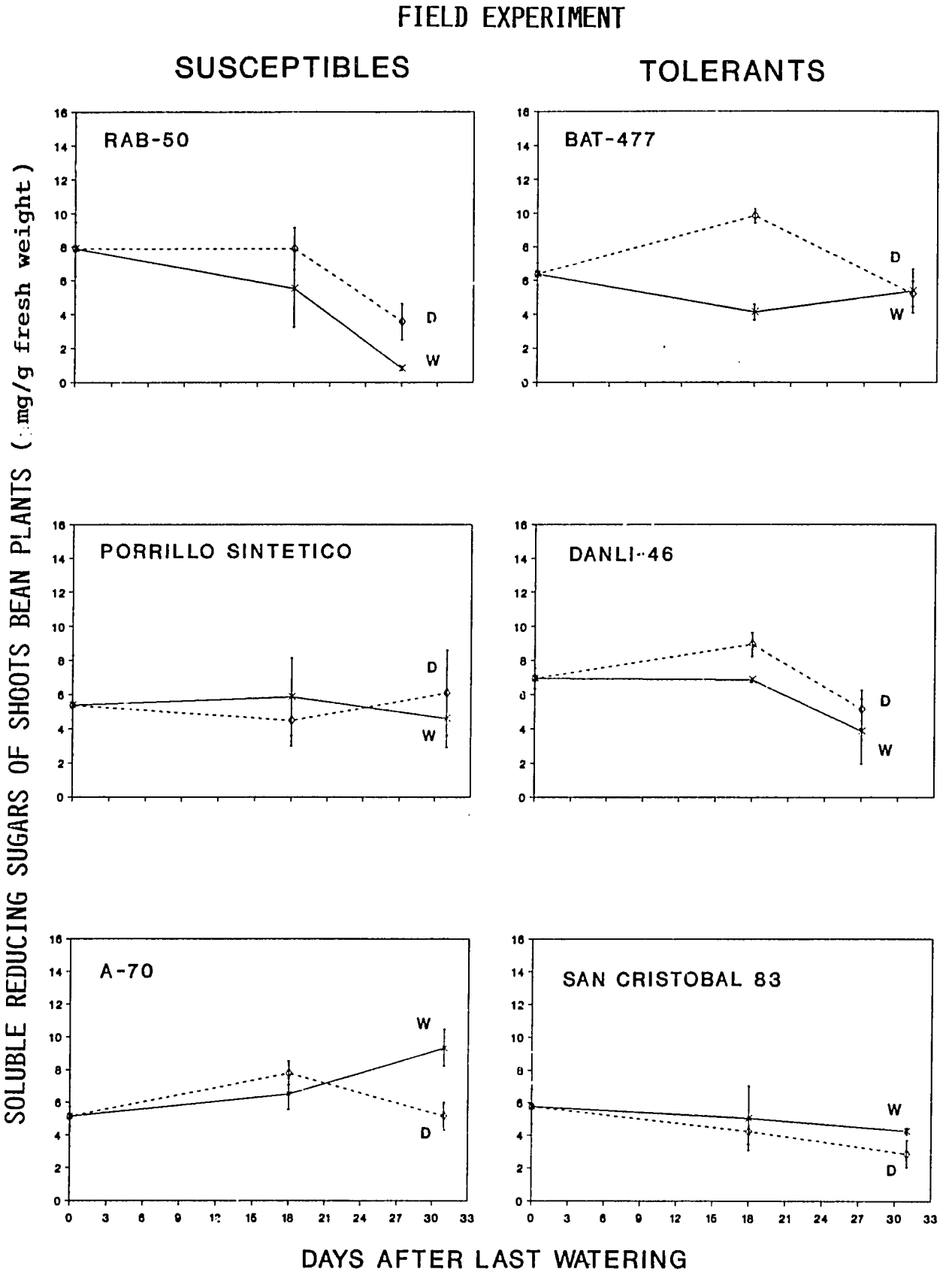
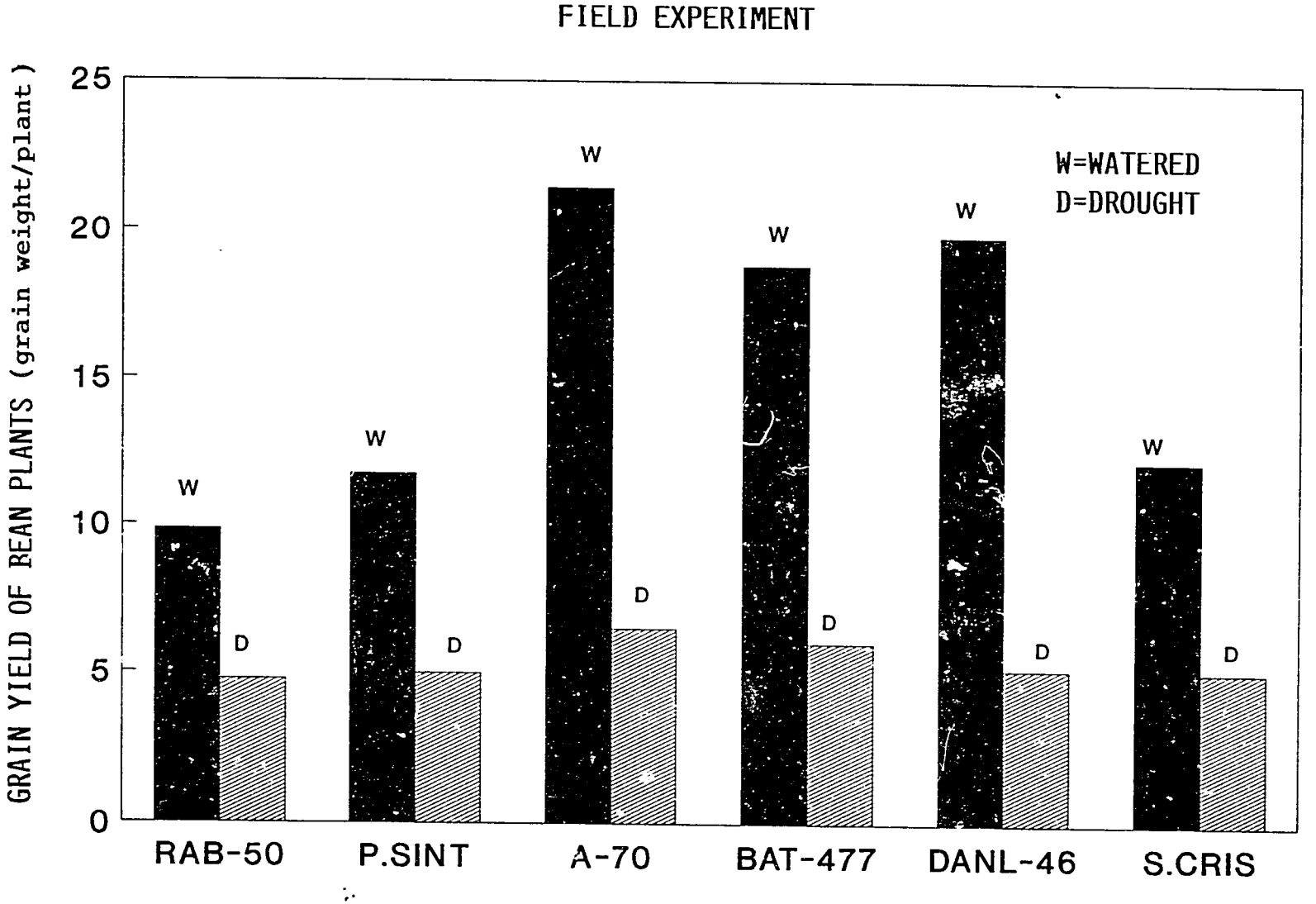

FIELD EXPERIMENT
SUSCEPTIBLES
TOLERANTS
RAB-50
BAT-477
PORRILLO SINTETICO
DANLI-46
A-70
SAN CRISTOBAL 83
D
W
SOLUBLE REDUCING SUGARS OF SHOOTS BEAN PLANTS (mg/g fresh weight)
DAYS AFTER LAST WATERING

Figure 30


FIELD EXPERIMENT
GRAIN YIELD OF BEAN PLANTS (grain weight/plant)
25
20
15
10
5
0
W=WATERED
D=DROUGHT
W
D
RAB-50
P.SINT
A-70
BAT-477
DANL-46
S.CRIS

IV. IMPACT, RELEVANCE AND TECHNOLOGY TRANSFER

The results of these studies have suggested that common bean genotypes respond to drought stress conditions very differently. Genotypes identified as drought tolerant under one set of conditions may not show clear differences with susceptible ones under another set of conditions. Conditions other than drought such as atmospheric and/or climatic differences presumably interact with the response of bean genotypes to drought stress (White and Izquierdo, 1991; Zuluaga *et al.*, 1988). To select bean germplasm for any region, it is necessary to screen a wide array of germplasm under diverse bean production conditions and systems in that region. Since most parameters included in our studies did not give a clear indication to be used as selection criteria for drought tolerance, tolerant genotypes should be selected in field trials using final yield *per se* as the main selection criteria (White and Singh, 1991); this selection approach can be done at low cost and in a short period of time. Selected tolerant genotypes under representative production conditions can be used as cultivars or as parents in breeding programs. Proline accumulation as an indicator should be included in future work.

These considerations are being taken into account in other drought projects recently initiated in Honduras and in the Central American region. Bean research program at Zamarano School of Agriculture continues in its efforts to improve beans for tolerance to drought in collaboration with the Universities of Minnesota and Puerto Rico, CIAT and the regional program ProFrijol. The expertise acquired under this project are being used to design and implement better programs.

V. PROJECT ACTIVITIES/OUTPUTS

Meetings attended under the project:

- PI visit to Honduras in 1987.
- Project coordination meeting in México, 7-8 May, 1990.
- XXXVIII PCCMCA (Central American Cooperative Program for the Improvement of Crops and Animals) Annual Meeting. Managua, Nicaragua, 23-27 March, 1992.
- International Crop Science Congress. Iowa State University, Ames, Iowa, 14-22 July, 1992.
- Two presentations were made at the National Research Council workshop on bean nitrogen fixation.
- One technical staff from Mexico was trained for four months at Rutgers.

VI. PROJECT PRODUCTIVITY

Despite a major setback involving the passing away of the original Co-PI in Honduras, Dr. Silvio Zuluaga, most of the project goals were met. Greenhouse and field experiments, comparing a set of tolerant and susceptible common bean genotypes were conducted to study drought tolerance mechanisms. The general reduction in plant growth and seed yield were very

obvious under stress conditions. However, our results are not very different from those obtained in previous studies with beans (Zuluaga *et al.*, 1988; White and Izquierdo, 1991) suggesting that an approach based on final yield conducted in representative bean production areas could be effective to identify tolerant materials (White and Singh, 1991).

VII. FUTURE WORKS

The funding for this project is terminated, therefore, no future work is planned.

VIII. LITERATURE CITED

Walker, D.W. and C.J. Miller, Jr. 1986. Rate of water loss from detached leaves of drought resistant and susceptible genotypes of cowpea. HortScience 21(1):131-132.

White, J.W. and S.P. Singh. 1991. Breeding for adaptation to drought. pp. 501-560. *In*: A. Van Schoonhoven and O. Voysest (eds.), Common Beans. Research for Crop Improvement. CAB International, UK.

White, J.W. and J. Izquierdo. 1991. Physiology of Yield Potential and Stress Tolerance. pp. 287-382. *In*: A. Van Schoonhoven and O. Voysest (eds.), Common Beans Research for Crop Improvement. CAB International, UK.

Zuluaga, S., C.M. Elvir, C. Rodríguez and J.D. Erazo. 1988. Investigaciones sobre tolerancia a sequía en frijol en Honduras. pp. 69-90. *In*: J.W. White, G. Hoogenboom, F. Ibarra and S.P. Singh (eds.), Research on Drought Tolerance in Common Bean. Documento de Trabajo No. 41, Bean Program, CIAT, Cali, Columbia.