WATER DEFICIT IMPOSED BY PARTIAL IRRIGATION AT DIFFERENT PLANT GROWTH STAGES OF COMMON BEAN (Phaseolus vulgaris L).

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Abstract.

The purpose of this study was to identify specific growth stages of common bean crop, at which the plant is less sensitive to water stress so that irrigation can be omitted without significant decrease in biological nitrogen fixation and final yield.
Two field experiments were conducted at "La Tola" University Experiment station, Tumbaco, Pichincha, Ecuador, on a sandy loam soil (Typic durustoll). The climate is warm and dry (mean air temperature 16 °C and mean relative humidity 74%) during the cropping season and rainfall of 123 mm was recorded during the cropping period (July to October , 1992 and 1994).
The treatments consisted of combinations of 7 irrigation regimes (I1=all normal watering; I2=all stress; I3= traditional practice; I4= single stress at vegetation; I5= flowering; I6= yield formation and I7= ripening stages) and 2 levels of applied N (20 and 80 kg/ha). These 14 treatment combinations were arranged and analysed in a split-plot design with 4 replications. The plot size was 33.6 m^2 (8 rows, 7 m long) and a plant population of 120,000 pl/ha was maintained.
Differential irrigation was started after 3 uniform irrigations for germination and crop establishment. Soil moisture was monitored with a neutron probe down to 0.60 m depth, before and 24 h after each irrigation. The actual evapotranspiration (ETa) of the crop was estimated by the water-balance technique. Field water efficiency (Ef=kg/m^3) and crop water use efficiency (Ec=kg/m^3) were calculated by dividing actual grain yield (10% seed humidity) by irrigation and by ETa, respectively. Biological Nitrogen Fixation was calculated using the N-15 metodology in the 20 Kg N/ha treatment.
From the yield data, it can be concluded that treatments which had irrigation deficit had lower yield than those that had suplementary irrigation (1% probability). The flowering stage was the most sensitive to moisture stress. Nitrogen fertilization significantly increased the number of pods and grain yield. Biological Nitrogen Fixation was significantly affected by water stress at flowering and yield formation stages.
The crop water use efficiency (kg/m^3) was the lowest at flowering period and the yield response factor (Ky) was higher in treatments I2 (all stres) and I5 (stress at flowering). Comparing with traditional practice by farmers of the region, only treatments I1 and I7 had 13 and 10% higher crop water use efficiency.

Introduction.-

Common bean (*Phaseolus vulgaris* L.) is an important crop in Latin America for its grain protein content. It has relatively shallow rooting depth, is a poor nodulator, requires frequent irrigation and large supplies of N fertilizers (Calvache 1991). The increasing demands for limited water suplies and rising costs of nitrogenous fertilizers require their economic application without adversely affecting production.

There is litle information regarding the effect of drought on Nitrogen fixation of common bean , however studies in other grain legumes suggest that N_2 fixation is sensitive to drought and even more so than NO_3^- reduction (Kirda et al., 1989; Saito et al ., 1984). An extended period of stress during the vegetative stage retards nodulation and depresses N_2 fixation (Smith et al., 1988; Saito et al. 1984; Zablotowicz et al., 1981). The loss of nodule activity is reversible if the nodules lose no more than 20% of the maximun fresh weigth (Sprent, 1971). Water stress during the reproductive stage reduce viable rhizobia in roots and yield (Kirda,et al. 1989; Espinosa-Victoria et al. 1985).

The objectives of this study were: To identify specific growth stages of common bean crop at which the plant is less sensitive to water stress, so that irrigation can be omitted without significant decrease in final yield and to determine how the irrigation deficit will affect fertilizer use efficiency, and biological nitrogen fixation, using N-15 methodology.

Materials and methods.

Two field experiments were carried out at "La Tola" Agricultural Experimental Station in Tumbaco, Pichincha, Ecuador on a Typic Durustoll soil sandy loam texture (16% clay; 0.8 % organic matter and pH 6.2)

Seven water stress treatments were studied at different growth stages (E1- Vegetative ; E2 - Flowering; E3 - Bean formation and E4 - Ripening period) and two levels of N-fertilizer aplied (F_1- 20 and F_2- 80 Kg/ha N). Two levels of Irrigation were imposed for water stress: 1) Normal watering when real evapotranspiration is equal to expected maximum (ETm) and 0) Deficit irrigation (1/2 ETm).

These 14 treatments combination were arranged as follows (table 1):

Table 1. Treatments combination

No.	Treatments	Growth Stage 1	2	3	4	Description
1	F1 I1	1	1	1	1	All normal watering
2	F1 I2	0	0	0	0	All stress (deficit irrigation)
3	F1 I3	..	..	..	..	Traditional practice
4	F1 I4	0	1	1	1	Single stress at vegetation
5	F1 I5	1	0	1	1	Flowering
6	F1 I6	1	1	0	1	Yield formation
7	F1 I7	1	1	1	0	ripening stages
8	F2 I1	1	1	1	1	All normal watering
9	F2 I2	0	0	0	0	All stress(deficit irrigation)
10	F2 I3	..	..	..	..	Traditional practice
11	F2 I4	0	1	1	1	Single stress at vegetacion
12	F2 I5	1	0	1	1	Flowering
13	F2 I6	1	1	0	1	Yield formation
14	F2 I7	1	1	1	0	ripening stages

Physical and chemical characterization of the soil and neutron probe calibration were carried out before actual experimental work was initiated. Seeds of bean cv Imbabello were planting on July 3/1992 and july 2/1994. Plots of 33.6 m^2, 8 furrows of 7 m (2 seeds per 25 cm) were distributed in a split-plot design, maitaining a plant population 120,000/ha. All the necessary data to calculate Penman reference evapotranspiration were collected from June to December 1992 and 1994. Immediately after the crop establishment period, irrigation was applied every week according to the experimental design. Soil water content was measured with a neutron probe from 20 to 60 cm with measurements every 10 cm. The actual evapotranspiration (ETa) of the crop was estimated by the water-balance technique. Field water efficiency (Ef=kg/m^3) and crop water use efficiency (Ec=kg/m^3) were calculated by dividing actual grain yield (10% seed humidity) by irrigation and by ETa, respectively (FAO 1977,FAO 1979)
Biological Nitrogen Fixation was calculated using N-15 metology in treatments F1, using the isotope dilution method (Fried & Middelboe, 1977). Bean plants were harvested according to their physiological stage at 120 dap, separated into pods and straw, dried at 65 °C weighted and ground. Sub samples were analysed for total N and N-15 isotope ratio by NOI6e analyzer. (FIEDLER & PROKSCH 1975).

Results and discussion.

The results of the physical analysis and the calibration curve of the neutron probe are shown in Table 2.

Table 2. Physical Analysis and Moisture Calibration Curve of the Soil (BD = BULK DENSITY ; PD = PARTICLE DENSITY; A= CALIBRATION INTERCEPT ; B = CALIBRATION SLOPE)

DEPTH (cm)	SAND (%)	SILT (%)	CLAY (%)	BD $g.cm^{-3}$	PD $g.cm^{-3}$	Por. (%)	A	B
0-28	72	12	16	1.45	2.62	44.7	+.009	.18
28-53	54	20	26	1.36	2.51	45.8	-.05	.21
53-84	56	22	22	1.37	2.55	46.2		
84-110	69	20	11	1.43	2.62	44.0		

Table 3 illustrates the data of crop evapotranspiration according to the modified Penman method and irrigation requirements applied to irrigation treatments.
From the yield data presented in Table 4 it can be concluded that treatments which had irrigation deficit have lower yields than those that had suplementary irrigation (1% probability). The flowering stage is the most sensitive to water stress. This treatment has the same result as the one which has water stress during the whole growing cycle in two experiments (1992 and 1994). Comparing the results of fertilized treatments it can seen that there are significant differences (1% probability) between the two fertilization levels used in two experiments (1992 and 1994).

The interaction between irrigation and fertilization was not statistically significant in first experiment (1992) and was statisticaly different in experiment 2 (1994).The highest value was obtained in the treatment I4F2. It can be seen that the lower yields are showed in treatment I5F2>I5F1>I2F2>I2F1.

Table 5 presents number of nodules per plant in different irrigation and fertilization treatments . It can be seen that there are not significant differences between treatments in experiment 1 (1992) but, in experiment 2 (1994) there are significant differences between irrigation treatments. All treatments under stress at sampling date have less number of nodules. Treatments 7, 6 and 1 have more number of nodules, probability because at sampling time they were not in water stress.

In Table 6 the percentage of nitrogen derived from the atmosphere and N Fixed in the different irrigation treatments can be seen. It is to be noted that treatments I1 (All normal watering), I4 and I7 (Stress at vegetation and ripening stages respectibly) have more N Fixed than the other and treatment I2 (All stress) has the lower value in experiment 1 (1992) and 2 (1994).

In Tables 7 and 8 soil water storage is shown down to the 50 cm depth during the period of two experiments (July to October 1992 and 1994). Water content increases after an irrigation or rain, according to the treatments. Water storage in treatment I2 is lower than treatment I1 (irrigation during the crop cycle). Generally water storage in all the treatments is higher than treatment I2 in the stages in which irrigation was made, but lower than in treatment I1 which received irrigation during the entire cycle.

Table 9 presents the final data for variables: actual yield (Ya), Irrigation (I), field water use efficiency (Ef), actual evapotranspiration (Eta), crop water use efficiecy (Ec) yield response factor (Ky) and relative yield response factor to compare two experiments. We can see that treatment I1 (all normal watering) and I7 (stress at ripening stage) have more Ec than the other due to the higher productivity. Treatment I2 (All stress) has Ef higher due to the small quantity of applied irrigation water during the crop's cycle. The Ky is higher in treatments I2 and I5, and lower in treatments I1 and I7 .

Comparing with traditional practice by farmers of the region, only treatments I4 and I7 had 13 and 10% higher crop water use efficiency.

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Table 3. **Crop Evapotranspiration and Irrigation Requirements**

Climate File : FREJTUM2					Climate Station: LA TOLA		
Crop : BEAN					Planting date : 2 July		
Month	Deca.	Stage	Coeff Kc	ETcrop mm/day	Eff.Rain mm/decad.	IRReq. mm/day	IRReq. mm/dec
Jul	1	init	0.35	1.60	0.2	1.57	11.0
Jul	2	init	0.35	1.61	0.0	1.61	16.1
Jul	3	deve	0.38	1.80	0.5	1.75	17.5
Aug	1	deve	0.54	2.68	1.0	2.58	25.8
Aug	2	deve	0.80	4.18	1.5	4.03	40.3
Aug	3	mid	1.04	5.22	4.5	4.77	47.7
Sep	1	mid	1.15	5.48	7.5	4.74	47.4
Sep	2	mid	1.15	5.29	10.4	4.25	42.5
Sep	3	late	1.11	5.00	15.3	3.47	34.7
Oct	1	late	1.02	4.47	22.1	2.25	22.5
Oct	2	late	0.90	3.88	28.0	1.08	10.8
Oct	3	late	0.79	3.34	22.2	1.13	11.3
Nov	1	late	0.68	2.82	4.5	1.33	4.0
TOTAL				449.1	117.6		331.4

ETm July 23 to October 20 = 374.5

Etm July 22 to November 08 = 400

Table 4. Number of pods per plant and yield at 14% Humidity (kg/ha)

FACTORS	1992		1994	
	No of pods	Yield (Kg/ha)	N° of pods	Yield (kg/ha)
IRRIGATION	(**)	(**)	(**)	(**)
I1	15.2 ab+	2723 a	24 ab	2772 b
I2	9.8 d	1207 d	15 d	2022 d
I3	13.7 b	2347 abc	19 c	2417 c
I4	14.1 b	2552 a	23 ab	2845 a
I5	11.1 cd	1840 c	19 c	2278 cd
I6	12.1 bc	2225 bc	21 bc	2704 b
I7	17.2 a	2542 a	24 a	2558 bc
FERTILIZATION	(**)	(**)	(*)	(*)
F1	12.7 b	2105 b	20 b	2470 b
F2	14.2 a	2386 a	21 a	2648 a
INTERACTION	(ns)	(ns)	(*)	(*)
I1F1	13.6	2321.5	23 ab	2628 de
I1F2	16.8	3125.5	24 ab	2916 bc
I2F1	10.3	1313.3	15 e	1870 h
I2F2	9.4	1101.2	16 de	2174 g
I3F1	13.7	2231.3	18 cd	2352 fg
I3F2	13.8	2463.6	20 c	2483 ef
I4F1	12.8	2377.3	23 b	2731 ab
I4F2	15.4	2727.1	24 ab	2951 a
I5F1	10.8	1818.2	19 c	2227 g
I5F2	11.4	1861.4	19 c	2329 fg
I6F1	11.9	2041.4	19 c	2667 cd
I6F2	13.9	2408.4	22 b	2740 cd
I7F1	15.7	2369.2	23 b	2510 def
I7F2	18.6	2715.8	25 a	2607 de
CV (%)	11.4	15.2	4	4

ns = no significan ;* = signifcant to 5%
** = significant to 1%
+ values followed by different letters are significantly different ($p<0.05$)

Table 5. Nodule number per plant during flowering stage under water stress treatments (1992, 1994).

FACTORS	1992	1994
	No. of nodules/plant	No of nodules/plant
IRRIGATION	(ns)	(*)
I1	74	53 ab
I2	45	30 b
I3	58	25 b
I4	68	35 b
I5	63	35 b
I6	67	52 ab
I7	58	72 a
FERTILIZATION	(ns)	(ns)
F1	60	51
F2	64	36
INTERACTION	(ns)	(ns)
I1F1	68	66
I1F2	80	39
I2F1	53	18
I2F2	37	42
I3F1	55	21
I3F2	62	29
I4F1	61	50
I4F2	74	21
I5F1	57	49
I5F2	69	22
I6F1	71	69
I6F2	67	35
I7F1	51	83
I7F2	64	62
C.V. (%)	19	47

ns = no significan ; * = significant to 5%
+ values followed by different letters are significantly different ($p<0.05$)

Table 6. Percentage of nitrogen derived from the atmosphere (%Ndfa) and N Fixed (kg/ha) in different irrigation treatments (Experiments 1992, 1994).

TREATMENTS	Bean (1992)		Bean (1994)	
	% Ndfa.	QNFix (kg/ha)	% Nda.	QNFix
IRRIGATION	(**)	(**)	(**)	(**)
No stress	55.5 a	51.7 ab	22.2 ab+	19.7 abc
All stress	27.7 b	15.3 c	7.8 b	4.9 c
Traditional	53.3 a	50.3 ab	24.0 a	20.4 ab
Vegetation	63.9 a	62.6 a	15.2 ab	13.7 abc
Flowering	55.8 a	39.6 b	17.0 ab	12.7 bc
Yi.fomation	58.2 a	43.1 ab	24.5 a	20.5 ab
Ripening	56.9 a	53.3 ab	27.5 a	20.5 ab
CV. (%)	15	18	31	37

ns = no significan ;* = signifcant to 5%
** = significant to 1%
+ values followed by different letters are significantly different ($p<0.05$)

Table 7. Water storage (mm) 50 cm depth

1992							
DAP	I1	I2	I3	I4	I5	I6	I7
20	94.56	95.78	103.95	88.93	95.31	98.20	98.83
25	89.77	96.86	96.63	85.81	87.80	90.09	87.83
32	92.82	94.89	97.62	87.18	89.59	92.68	92.13
39	101.55	97.21	105.99	106.38	103.27	97.78	101.06
43	118.17	89.17	114.31	101.30	109.50	101.44	105.03
48	128.21	97.17	120.83	99.44	121.72	110.17	120.09
55	114.46	89.99	104.00	94.98	105.90	105.02	104.26
62	108.44	90.26	92.85	89.60	95.85	99.75	99.06
69	112.13	91.63	90.45	93.27	92.82	95.55	101.34
76	121.18	96.60	104.14	108.22	103.33	101.40	121.73
82	108.98	92.12	94.43	98.12	98.87	92.18	106.62
89	121.50	94.30	103.55	105.36	106.41	92.30	116.05
96	115.20	87.19	98.91	100.32	106.69	87.47	106.84
103	150.23	130.13	146.85	151.11	142.12	135.40	116.49
111	119.40	101.89	114.20	127.83	114.78	112.14	108.24

Table 8. Water storage (mm) 50 cm depth

1994							
DAP	I1	I2	I3	I4	I5	I6	I7
23	134.57	130.96	129.71	126.72	130.73	129.46	135.71
32	134.52	130.93	127.30	127.41	128.95	125.83	129.33
40	134.29	121.16	124.08	121.40	129.75	122.47	126.76
46	135.40	116.34	123.74	117.18	131.37	128.54	142.32
53	142.69	116.83	122.06	113.47	132.36	130.80	138.83
59	145.10	110.80	116.96	121.10	124.20	130.30	124.62
66	134.43	103.86	117.66	117.35	109.38	119.68	126.11
74	122.47	104.30	104.20	112.60	103.96	112.92	116.25
81	113.09	97.10	101.42	107.83	99.65	100.05	110.53
88	129.72	116.76	113.19	124.74	118.77	106.27	125.51
94	111.41	123.56	106.81	112.90	110.10	109.74	110.23
102	131.37	101.05	119.12	129.65	129.12	102.35	124.64
108	114.12	96.58	108.57	115.89	113.44	97.99	108.13
115	107.37	96.78	101.72	109.65	106.16	103.02	98.06
121	117.00	95.18	106.18	116.55	115.56	110.87	94.65
128	126.38	96.18	110.28	128.28	124.86	125.35	96.06

Table 9. Actual Yield 10%H (Ya=kg/ha),Irrigation (I=mm/period), Field water efficiency (Ef=kg/m^3),Actual Evapotranspiration (Eta=mm), Crop Water Use Efficiency (Ec=kg/m^3), Relative Evaporation Deficit (Ky)

1992									
Treatment	Ya	I	Ef	ETa	Ec	1-ETa/ETm	1-Ya/Ym	Ky	Kyrelative
I1	2187	207	1,06	289	0,76	0,03	0,01	0,03	0,02
I2	770	44	1,75	204	0,38	0,46	0,65	1,43	1,00
I3	1734	138	1,26	259	0,67	0,31	0,21	0,68	0,48
I4	1908	154	1,24	287	0,66	0,23	0,13	0,57	0,40
I5	1303	143	0,91	261	0,50	0,30	0,41	1,34	0,94
I6	1686	141	1,20	274	0,62	0,27	0,23	0,87	0,61
I7	2112	193	1,09	286	0,74	0,24	0,04	0,17	0,12
1994									
Treatment	Ya	I	Ef	ETa	Ec	1-ETa/ETm	1-Ya/Ym	Ky	Kyrelative
I1	2611	297	0,88	352	0,74	0,04	0,01	0,10	0,02
I2	1804	55	3,28	260	0,69	0,37	0,32	0,87	1,00
I3	2269	155	1,46	272	0,83	0,34	0,14	0,43	0,49
I4	2528	214	1,18	324	0,78	0,21	0,05	0,22	0,25
I5	2148	210	1,02	268	0,80	0,35	0,19	0,55	0,63
I6	2421	292	0,83	346	0,70	0,16	0,09	0,55	0,64
I7	2422	244	0,99	309	0,78	0,25	0,09	0,35	0,40