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Plant water relations and nutrient uptake in French bean*

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Summary. Field investigations carried out at the Indian Institute of Horticultural Research, Bangalore, during 1985–1986 and 1986–1987 with French bean crops indicated that irrigation when soil matric potential at 0.15 m depth reached −45 kPa resulted in highest dry matter production, green pod yield, nutrient uptake and water use efficiency (WUE) as compared to irrigations scheduled at −65 or −85 kPa. The difference in pod yield between irrigations scheduled at −25 and −45 kPa was not significant. Increasing soil moisture stress increased the canopy temperature and adversely affected plant water relations. There was a quadratic relationship between green pod yield and evapotranspiration (ET) with the yield-maximising ET ranging between 268 and 299 mm. Nitrogen fertilization significantly increased green pod yield, nutrient uptake and WUE but had no marked effect on water relations and canopy temperature.

French bean (*Phaseolus vulgaris* L.) is an important legume vegetable cultivated throughout India for its green pods. It has relatively shallow rooting depth, is a poor nodulator (Habbish and Ishaq 1974), requires frequent irrigations (Maurer et al. 1969; Miller and Gardner 1972; Stansell and Smittle 1980; Weaver et al. 1984) and large supplies of N fertilizers (Srinivas and Rao 1984). The increasing demands for limited water supplies in arid and semiarid regions coupled with rising costs of nitrogenous fertilizers necessitate economic application without adversely affecting production. Water requirement of French bean has received very little attention and, therefore, the purpose of this study was to evaluate the effects of soil matric potentials and N fertilization on plant water relations, canopy temperature, green pod yield, nutrient uptake and water use of French bean.

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Materials and methods

The field experiments were conducted at the Indian Institute of Horticultural Research, Hessaraghatta, Bangalore, during the winter seasons of 1985–1986 and 1986–1987 on sandy clay loam soils (Udic Haplustalf) of low fertility (organic carbon 0.46%, available P 9.7 kg/ha; available K 131.5 kg/ha; pH 6.8). The soil had the capacity to hold 0.136 m available water in the top 0.9 m soil profile. The climate was warm and dry during the cropping season (Table 1) and a rainfall of 29 and 37 mm was recorded during the cropping period of 1985–1986 and 1986–1987, respectively. The water table was below 3 m during the cropping season in both years and hence ground water contribution to the root zone was considered negligible.

The treatments consisted of all combinations of irrigations at 4 soil matric potentials (−25, −45, −65 and −85 kPa at 0.15 m depth) and 4 levels of applied N (0, 40, 80 and 120 kg/ha). These 16 treatment combinations were arranged and analysed in a randomised block design with 3 replications. Half of the N was applied prior to seeding as urea along with uniform level of 80 kg P_2O_5 (single super phosphate) and 40 kg K_2O (Muriate of potash) and the remaining half of the N was side dressed 25 days later. Seeds of French bean (cv. 'Arka Komal') were planted every 0.1 m on ridges 0.5 m apart on the 22nd and 18th of November during 1985–1986 and 1986–1987, respectively. After emergence, one seedling was retained at each location maintaining a plant population of 200,000/ha. The plot size was 13.6 m^2 (8 rows, 3.4 m long). Green pods were picked at regular intervals from an area of 9 m^2 (6 rows, 3 m long) and the marketable yield of green pods was estimated on weight basis.

Soil matric potential was monitored by installing jetfill tensiometers at 0.15 m depth between 2 plants in a crop row. Differential irrigations were started after 3 uniform irrigations for germination and establishment. soil moisture was monitored with a neutron probe up to 0.9 m depth before and 48 h after each irrigation. The soil moisture at the time of seeding and final harvest was also estimated and the total evapotranspiration (ET) of the crop was estimated by the water-balance technique. Drainage or upward flow from ground water was not considered to cause significant error in the estimate of ET. Water use efficiency (WUE) was calculated by dividing marketable green pod yield by ET. Leaf area was measured 8 weeks after emergence and leaf area index (LAI) was computed.

A sample of 4 plants was collected at the time of final harvest to determine dry matter and nutrient content in leaf and stem. Dry weight of pods harvested during different pickings from 4 randomly tagged plants was used to determine dry matter and nutrient content in pods. Ground composite samples were used for estimating N, P and K concentrations according to methods described by Jackson (1967) only during 1985–1986. Uptake of all the nutrients was calculated using data on their concentrations and dry matter yield.

Leaf water potential (LWP) was determined for one irrigation cycle during 1985–1986. LWP and Osmotic Potential (OP) were also determined on the day when irrigation schedules for all the 4 soil matric potentials coincided in 1985–1986. The plants were exposed to 5, 8, 11 and 15 days of deficit prior to the measurement day. A recently matured leaf was excised around noon time (11.30–12.30 h) and LWP was measured with a pressure chamber as desribed by Sivakumar and Virmani (1979). OP was determined with a Wescor 5100 Vapour Pressure Osmometer. For this, leaf samples were placed in a deep freeze (−20 °C) overnight, thawed for 5 min and pressed to extract the sap. Turgor potential (TP) was calculated as the difference between LWP and OP.

Canopy temperature was measured between 12.00 and 13.00 h using a Barnes infrared thermometer (Model 14-220D-i) for one irrigation cycle during 1985–1986. The instrument was held at an angle of 45° to the crop surface at a distance of 0.9 m so as to obtain canopy temperature minimally influenced by the underlying soil. The instrument provided 28° field of view and a target size of 0.6 m.

Results and discussion

Plant water relations

Irrigation at different soil matric potentials significantly influenced plant water relations in French bean (Fig. 1, Table 2). Changes in LWP over one irrigation cycle indicated a gradual but continuous decline in LWP with each succeeding day after irrigation. How-

Table 2. Leaf water potential, osmotic potential and turgor potential of French bean as affected by soil matric potential and N fertilization

Treatment	Leaf water potential (MPa)	Osmotic potential (MPa)	Turgor potential (MPa)
Soil matric potential			
−25 kPa	−0.58	−1.10	0.52
−45 kPa	−0.68	−1.19	0.51
−65 kPa	−0.82	−1.24	0.42
−85 kPa	−0.93	−1.30	0.37
LSD (P=0.05)	0.10	0.13	0.08
N Levels (kg/ha)			
0	−0.73	−1.17	0.44
40	−0.76	−1.20	0.44
80	−0.75	−1.23	0.48
120	−0.77	−1.22	0.45
LSD (P=0.05)	NS	NS	NS

NS = No significant difference observed

Table 1. Weather data recorded during cropping season of 1985–86 and 1986–87

Month	Mean air temperature (°C)		Mean relative humidity (%)	Mean Class A Pan evaporation (mm/day)	Total rainfall (mm)
	Maximum	Minimum			
	1985–86				
November, 1985	26.6	16.6	67.5	3.6	44.0
December, 1985	27.3	16.3	64.0	4.2	1.2
January, 1986	26.1	14.1	69.2	4.2	29.0
February, 1986	29.0	16.3	52.3	5.3	18.3
	1986–87				
November, 1986	26.7	16.3	71.3	3.8	82.3
December, 1986	26.5	15.2	71.5	4.3	37.2
January, 1987	25.8	13.6	68.1	4.5	–
February, 1987	27.8	13.1	57.3	6.1	–

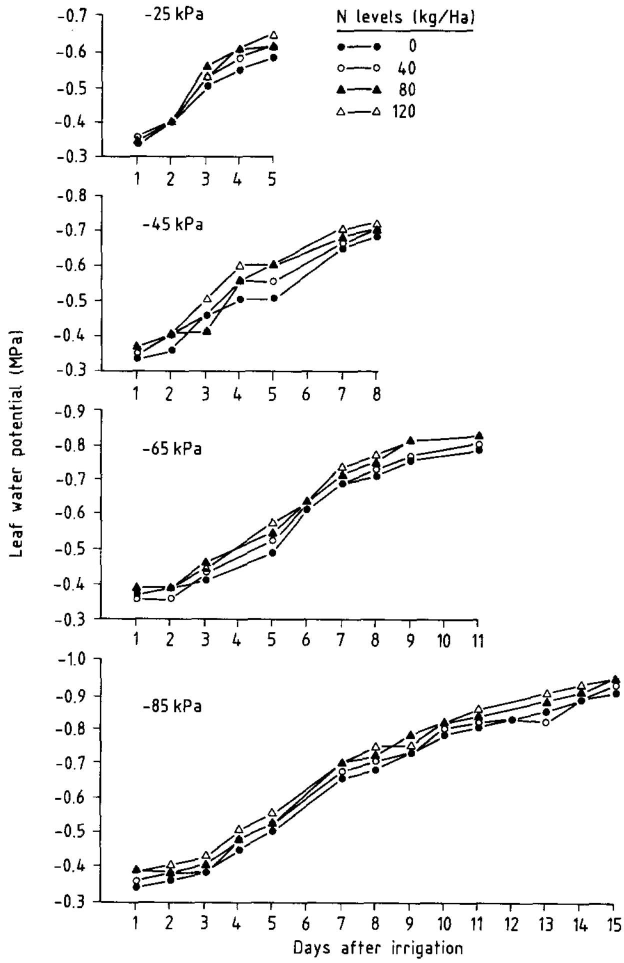

Fig. 1. Changes in leaf water potential in French bean in relation to irrigation and N fertilization

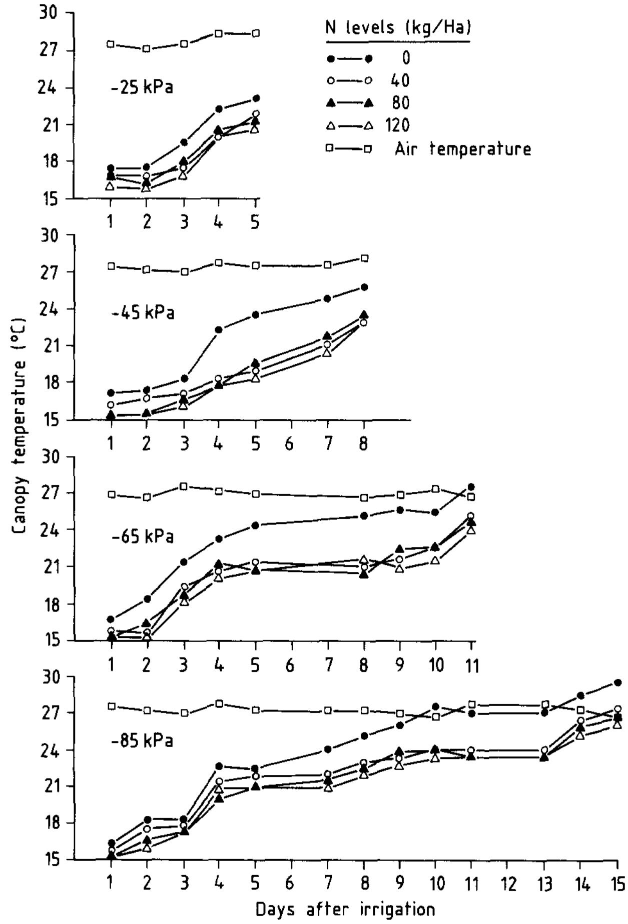

Fig. 2. Changes in canopy temperature in French bean in relation to irrigation and N fertilization

ever, the reduction in LWP on the day of irrigation was maximum with irrigation at −85 kPa. LWP was estimated on the day when the irrigation schedules for all the 4 soil matric potentials coincided. Frequent irrigation at −25 kPa was associated with the highest LWP, which, as expected, declined with decreasing frequency of irrigation. Osmotic potential followed a trend similar to that of LWP thereby limiting the decline in TP. Major reductions in TP below some threshold value have been associated with reductions in growth (Green et al. 1971) and may interfere with many biochemical processes (Hellebust 1976). Adjustment of OP is one of the mechanisms whereby plants may adopt to deficit water supply. In French bean, OP declined with decline in LWP. This enabled the plants to maintain a near constant TP when frequency of irrigation was reduced from −25 to −45 kPa. However, when irrigations were scheduled at −65 kPa or −85 kPa, the decline in OP was not enough to maintain TP constant. Similar types of osmotic adjustment have been reported in other vegetable crops such as egg plant (Behboudian 1977) and tomato (Rao 1985). Nitrogen fertilization had no significant effect on plant water relations in French bean. The interaction effects also were not significant.

Canopy temperature

Canopy temperature in French bean was markedly influenced by irrigation at different soil matric potentials (Fig. 2). In general, there was an increase in canopy temperature with each day after irrigation. Maximum canopy temperature was observed with irrigation at −85 kPa and declined with increasing irrigation frequency. This is probably related to the volume of soil water available for transpiration. When soil moisture becomes limited, stomatal closure occurs resulting in reduced transpiration, increased heat load on the canopy and a consequent rise in canopy temperature (Pearey et al. 1971). There was conspicuous reduction in canopy temperature with N application

Table 3. Dry matter, leaf area index and green pod yield of French bean as affected by soil matric potential and N fertilization

Treatment	Total dry matter yield (g/plant)		Leaf area index		No. of pods/plant		Green pod yield (kg/ha)	
	1985–86	1986–87	1985–86	1986–87	1985–86	1986–87	1985–86	1986–87
Soil matric potential								
−25 kPa	22.3	24.1	2.58	2.76	8.4	8.9	11,069	11,233
−45 kPa	22.6	25.3	2.62	2.81	8.3	9.1	12,451	11,858
−65 kPa	20.9	23.0	2.54	2.70	7.0	7.6	10,467	10,012
−85 kPa	18.7	19.6	2.32	2.39	6.0	6.3	8,787	8,347
LSD (P=0.05)	0.8	1.6	0.05	0.06	1.2	1.1	1,467	1,058
N Levels (kg/ha)								
0	13.8	13.0	1.76	1.62	6.0	5.6	7,504	5,868
40	20.6	22.3	2.44	2.78	7.3	7.5	11,044	10,083
80	24.3	27.1	2.87	3.12	8.0	9.0	11,792	12,269
120	25.8	28.6	3.00	3.14	8.4	9.8	12,435	13,231
LSD (P=0.05)	0.8	1.6	0.05	0.05	1.2	1.1	1,467	1,058

Table 4. N, P and K uptake (kg/ha) in French bean as affected by soil matric potential and N fertilization

Treatments	N				P				K			
	Leaf	Stem	Pod	Total	Leaf	Stem	Pod	Total	Leaf	Stem	Pod	Total
Soil matric potential												
−25 kPa	43.0	16.4	62.7	112.1	6.4	2.7	10.3	19.4	28.4	16.0	52.4	96.8
−45 kPa	47.3	18.8	64.0	130.1	6.3	2.9	10.5	19.7	30.0	18.3	55.0	103.3
−65 kPa	46.6	14.8	58.4	120.8	6.0	2.4	9.5	17.9	27.6	14.7	53.0	95.3
−85 kPa	42.8	14.1	52.8	109.7	5.4	2.2	7.6	15.2	23.3	12.8	44.9	81.0
LSD (P=0.05)	2.8	1.3	5.5	5.4	0.5	0.2	0.6	1.4	2.3	1.5	3.9	4.9
N Levels (kg/ha)												
0	31.7	10.0	39.3	81.0	4.4	1.7	6.0	12.1	19.8	9.5	33.6	62.9
40	42.0	15.3	60.5	117.8	5.8	2.4	9.7	17.9	25.3	14.8	51.5	91.6
80	51.8	17.9	65.2	134.9	6.6	3.0	10.9	20.7	29.5	18.1	58.1	105.7
120	54.1	20.9	73.9	148.9	7.2	3.2	11.2	21.6	34.7	19.4	62.0	116.1
LSD (P=0.05)	2.8	1.3	5.5	5.4	0.5	0.2	0.6	1.4	2.3	1.5	3.9	4.9

which was probably due to the increased leaf area (Table 3) which acted as a buffer against large fluctuations in canopy temperature.

Dry matter and green pod yield

Maximum dry matter and green pod yield were recorded with irrigation at −45 kPa (Table 3); similar values to those recorded with most frequent irrigation at −25 kPa. These yields were significantly higher than with irrigations at −65 and −85 kPa. Irrigation at −85 kPa resulted in lowest dry matter and green pod yield. French bean requires frequent irrigations and soil matric potential of −25 to −50 kPa was reported to be optimum (Miller and Gardner 1972; Stansell and Smittle 1980). The differences in green pod yield among irrigation treatments could be attributed to the significant variations in the number of pods per plant.

There was significant increase in dry matter production with N fertilization up to 120 and 80 kg/ha in 1985–1986 and 1986–1987 respectively. Green pod yield followed similar trend although the increases were significant only up to 40 and 80 kg N/ha in 1985–1986 and 1986–1987. French bean being a poor nodulator, response to application of N could be expected (Habbish and Ishaq 1974; Srinivas and Rao 1984). The improvement in yield with N fertilization was brought about by significant increase in the number of pods per plant. There was no significant interaction effect.

Nutrient uptake

Irrigation regimes exerted significant influence on nutrient uptake by French bean (Table 4). The total N uptake and its distribution into different parts was

Table 5. Evapotranspiration and water use efficieny of French bean as affected by soil matric potential and N fertilization

Treatments	Irrigation water applied (mm)		Evapotranspiration		Water use efficiency (kg/M^3)	
	1985–86	1986–87	1985–86	1986–87	1985–86	1986–87
Soil matric potential						
−25 kPa	520	480	272	295	4.1	3.8
−45 kPa	400	400	268	286	4.6	4.2
−65 kPa	320	320	251	273	4.2	3.7
−85 kPa	280	280	236	254	3.7	3.3
N Levels (kg/ha)						
0	380	370	245	259	3.1	2.3
40	380	370	248	267	4.4	3.8
80	380	370	210	290	4.4	4.2
120	380	370	264	292	4.8	4.5

highest with irrigation at a soil matric potential of −45 kPa while it was lowest with most infrequent irrigation at −85 kPa. N uptake decreased due to large reduction in dry matter production although N concentration increased with lower soil matric potential. Total P uptake was higher with frequent irrigations at −25 to −45 kPa. Phosphorus uptake declined with decreasing frequency of irrigation which was generally associated with reduced dry matter production. Irrigation at −45 kPa also resulted in maximum K uptake followed by irrigation at −45 and −65 kPa. Significantly lowest K was recorded with irrigation at −85 kPa. Reduced K uptake with infrequent irrigation was associated with both reduced K concentration and dry matter production. Since much K moves by mass flow and diffusion, its reduced mobility leading to reduced uptake may be expected under lower soil matric potential (Oliver and Barber 1966). The interaction between irrigation and N was not significant on nutrient uptake.

Water use

Water use of French bean was markedly influenced by irrigation treatments (Table 5). There was a decline in ET with decreasing soil matric potential. This could be due to a combination of both reduced surface soil evaporation with lower irrigation frequency and greater plant water deficits in low soil matric potentials culminating in reduced transpiration. WUE, however, was maximum with irrigation at −45 kPa and declined with both increasing and decreasing irrigation frequency. At low soil matric potential of −65 and −85 kPa, decreases in ET were of smaller magnitude than those in green pod yield resulting in lower WUE.

Nitrogen fertilization marginally increased ET probably due to higher leaf area that increased the transpiration losses. WUE, however, increased with increasing level of N fertilization up to 120 kg/ha as the increases in yields were larger than that in ET.

Regression equations fitted between green pod yield (Y) and ET indicated a quadratic relationship during both years:

$$1985\text{–}1986 \quad Y = -200258 + 1582.11\ \text{ET} - 2.95\ \text{ET}^2.$$
$$1986\text{–}1987 \quad Y = -132682 + 964.26\ \text{ET} - 1.61\ \text{ET}^2.$$

Where, Y is in kg/ha and ET is in mm. The coefficients of determination (R^2) were 0.85 and 0.91 during 1985–1986 and 1986–1987, respectively. The yield maximising level ET is found to be 268 and 299 mm during 1985–1986 and 1986–1987 respectively.

Conclusions

Irrigating French bean at a soil matric potential of −45 kPa at 0.15 m depth resulted in highest green pod yield and water use efficiency, maintaining more favorable plant water relations as compared to irrigation at −65 or −85 kPa. Nitrogen fertilization up to 40 to 120 kg/ha significantly increased green pod yield and water use efficiency.

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References

Behboudian MH (1977) Response of eggplant to drought I. Plant water balance. Scientia Hortic 7:303

Green PB, Erickson RD, Buggy J (1971) Metabolic and physical control of cell elongation rate. In vitro studies in Nitella. Plant Physiol 47:423

Habbish HA, Ishaq HM (1974) Nodulation of legumes in Sudan III. Response of haricot bean to inoculation. Exp Agric 10:45

Hellebust JA (1976) Osmoregulation. Annu Rev Plant Physiol 27:485

Jackson ML (1967) Soil chemical analysis. Prentice Hall, Ltd. New Delhi

Maurer AR, Ormord DP, Scott NJ (1969) Effect of five soil-water regimes in growth and composition of snap beans. Can J Plant Sci 49:271

Miller AA, Gardner WR (1972) Effect of soil and plant water potentials on the dry matter production of snap beans. Agron J 64:559

Oliver S, Barber SA (1966) An evaluation of the mechanism governing the supply of Ca, Mg, K and Na to soybean roots (*Glycine max*). Soil Sci Soc Am Proc 30:80

Pearcy RW, Bjorkman D, Harrison AT, Mooney HA (1971) Photosynthetic performance of two desert species with C-4 photosynthesis in death valley. California, Carnegie Institute Washington Year Book 70:540

Rao NKS (1985) The effect of anti-transpirants on leaf water status, stomatal resistance and yield in tomato. J Hort Sci 60:89

Sivakumar MVK, Virmani SM (1979) Measuring leaf water potential in chickpea with a pressure chamber. Exp Agric 15:377

Srinivas K, Rao JV (1984) Response of French bean to nitrogen and phosphorus. Indian J Agron 29:146

Stansell JR, Smittle DA (1980) Effects of irrigation regimes on yield and water use of snap bean (*Phaseolus vulgaris* L.). J Am Soc Hort Sci 105:869

Weaver NGH, Burke DW, Silbernagel HJ, Foster K, Timm H (1984) Effect of soil moisture tension on pod retention and seed yield of bean. Hort Sci 14:567