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ECONOMICS OF WATER USE IN VEGETABLE PRODUCTION : A CASE STUDY OF BRINJAL*

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Water is the most important and often limiting input factor in the production of crops. So it is necessary to use it in a rational manner. This requires a thorough knowledge of the water-yield relationship and its range of substitutability with other inputs. In this paper an attempt was made to study these relationships. The specific objectives of the paper are (i) to estimate the yield-water–fertilizer relationship (ii) to study the productivity of water and fertilizer inputs (iii) to know the extent of substitutability of these two inputs and (iv) to find out the optimum combination of these inputs for maximizing the profit under different price situations.

Materials and Methods

The data for this study were obtained from an experiment conducted on brinjal (*Solanum malongena* L.) at the experimental farm of the Indian Institute of Horticultural Research, Hessaraghatta during summer 1977. The experiment consisted of four irrigation treatments (irrigation at 20, 40, 60 and 80% available soil moisture) at four levels of nitrogen (0, 50, 100 and 150 kg/ha) in a factorial randomised block design with three replications for each treatment. Phosphorus and potassium at 30 kg/ha were applied to all plots. The irrigations under different moisture regimes were scheduled on the basis of soil moisture depletion in the 0-60 cm soil layer determined gravimetrically. Other cultural operations were same for all treatments.

a) *Selection of functional form* :

The quadratic type of response function proposed by Hexem and Heady (1978) was selected for estimating the plant-water-fertilizer relationship.

$$Y = a + b_1W + b_2N - b_3W^2 - b_4N^2 + b_5WN \quad \ldots\ldots\ldots\ldots(1)$$

where Y — yield in kg/ha, W — water application in cm and N = nitrogen in kg/ha.

b) *Marginal productivities of the inputs :*

The marginal productivity of the two inputs viz., water and nitrogen were obtained by taking partial derivatives of Y with respect to W and N from equation (1)

$$\partial y / \partial w = b_1 - 2b_3W + b_5N \quad \ldots\ldots\ldots\ldots(2)$$

$$dv!\ \partial n = b_2 - 2b_4N + b_5W \quad \ldots\ldots\ldots\ldots(3)$$

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c) *Marginal rate of substitution :*

The marginal rate of substitution between water and nitrogen was calculated by finding out the optimum quantity of water required for given levels of nitrogen for producing a predetermined levels of yield with the help of iso-quant (Heady and Dillon, 1961) obtained from equation (1)

$$W = \frac{b_1 + b_5 N \pm [(b_1 + b_5 N)^2 - 4 b_3 (Y + b_4 N^2 - b_2 N - a)]}{2 b_3} \cdots$$

and using these levels of inputs in the following equation

$$\text{MRS of N for W} = \frac{\partial N}{\partial N} = \frac{b_2 - 2b_4 N + b_5 W}{b_1 - 2b_3 W + b_5 N} \cdots\cdots\cdots\cdots (5)$$

d) Economic optimum input use levels :

Economically optimum levels of water and nitrogen inputs were found under the assumption that the goal is profit maximisation. So the objective function can be stated as,

$$\Pi = P_y Y = (P_W W + P_n N) - FC \ldots\ldots\ldots\ldots (6)$$

where P_y , P_w and P_n are price per unit of produce, water and nitrogen respectively and F. C. represents fixed costs. Y is is the output which is given by equation (1) and W and N are quantities of water and nitrogen used respectively. Setting the first order derivatives of equation (6) with respect to W and N equal to zero, a system of two equation are obtained.

$$d\Pi / \partial W = P_y \ \partial Y / \partial W - P_W = 0 \ldots\ldots\ldots\ldots\ldots (7)$$

$$\partial \Pi / \partial N = p_y \ \partial Y / \partial N - p_n = 0 \ldots\ldots\ldots\ldots\ldots (8)$$

Solving this system of equations stimultaneously we have the quantities each of W and N that will maximize profits relative to fixed resources. By substituting these values back in equation (1), we estimate the Y, yield consistent with profit maximisation.

Results and Discussion

As the data was obtained from a field experiment, it was subject to the usual statistical analysis before fitting the production function. From the results of the analysis of variance of yield data (ANOVA) and means presented in Table 1, it could be observed that both the inputs viz., irrigation and nitrogen and their interactions were highly significant.

The fitted quadratic response function for the experimental data was,

$$Y = 19197.2927 + 825.5274 W^{**} + 37.9516 N - 5.5463 W^{2**} - 0.5798 N^{2**} + 1.6066 WN^{**}$$

R^2 = 0,94 and $F = 32.15^{**}$

where Y - yield kg/ha, W - water in cm, and N - nitrogen kg/ha.

The equation shows that all the coefficients have the expected signs and except linear term of nitrogen, all others are significant at 1% level. These two inputs could also explain 94 per cent of variation in the yield.

Figure 1 presents the response of nitrogen to specific levels of water based on the above response function. From the figure it could be observed that using 80 cm of water per hectare will give the highest production when no fertilizer was applied as fertilizer was increased it was also desirableto increase the application of water for getting higher yields, and maximum production was obtained with use of water around 100 cm and that of nitrogen around 175 kg. The exact input levels required for achieving maximum production can be determined by equating partial derivatives of Y with respect to W and N to zero i. e. $\partial y / \partial w = 0$ and solving these equations simultaneously gives the input levels, which can be used in the original equation to obtain the maximum yield. The quantities of water and nitrogen based on the above procedure were 99 cm and 170 kg respectively and the yield was 249 quintals per hectare.

Marginal productivity of water and nitrogen:

The marginal productivity (MP) of water and nitrogen which shows the contribution of each additional dose of input to output at fixed levels of the other inputs is presented in Figure 2 and 3. [MP_w = 825.5274 — 11.0926 W + 1.6066N

Table 1

Results of statistical analysis of the experimental data on brinjal

a) ANOVA

Source	DF	M. S.	F
Replications	2	—	—
Irrigation (I)	3	90.1411	28.40''
Nitrogen (N)	3	171.9437	54,17''
Interaction (IxN)	9	16.1602	5.09**
Error	30	3.1740	—
Total	47	—	—

** Significant at 1% level.

b) MEANS (kg/plot of 5 x 1.8m)

	No	N_1	N_2	N_3	Mean
I_1	8.78	16.34	19.72	21.34	16.55
I_2	8.88	14,68	18.66	21.28	15.87
I_3	8.25	13.05	15.01	13.31	12.41
I_4	7.9!	13.21	11.08	11.15	10.84
Mean	8.45	14.32	16.12	16.77	

c) SEM & CD:

Item	I	N	IxN
SEM	0.51	0.51	1.03
CD at 5%	2.00	1.48	2.97

Table 2

Combinations of nitrogen and water required to produce specified brinjal yields and corresponding marginal rates for substitution

N (kg)	Y = 5000		Y = 10,000		Y = 15,000		Y = 20,000	
	W (cm)	MRS (∂ w/ 0 n)	W (cm)	MRS (∂ w/ ∂ N)	W (cm)	MRS (∂ w/ ∂ N)	W (cm)	MRS (∂ w/ ∂ N)
0	40.13	0.2693	57.86	0.7126	—*	—	—*	—
25	35.22	0.1380	47.51	0.2518	72.51	2.0443	—*	—
50	32.81	0,0603	43.12	0.1152	57.50	0.2699	—*	—
75	32.03	0.0413	41.30	0.0355	53.10	0.1020	73.83	0.5478
100	—	—	—	—	51.79	0.0126	67.09	0.1231

* The value for the square-root term has become negative and hence square root could not be taken. This can be taken to mean that this quantity cannot be produced with nitrogen levels indicated against them.

Table 3

Optimum combination of water and nitrogen for specific price relationships

Price situation	Optimum yield (q/ha)	Optimum use of water and nitrogen	
		Water (cm/ha)	Nitrogen (kg/ha)
A. *Brinjal at Rs 0.60/kg and nitrogen at Rs 4.52/kg*			
i) Water at Rs 5.06/ha cm	248.60	96.91	160.49
ii) Water at Rs 9.02/ha cm	248.44	96.16	159.46
iii) Water at Rs 24.86/ha cm	247.29	93.18	255.34
B. *Brinjal at Rs 0.60/kg and nitrogen at Rs 5.11/kg*			
i) Water at Rs 5.06/ha cm	248.51	96.75	159.43
ii) Water at Rs 9.02/ha cm	248.33	96.01	158.40
iii) Water at Rs 24.86/ha cm	247.14	93.03	154.27
C. *Brinjal at Rs. 1.20/kg and nitrogen at Rs 4.52/kg*			
i) Water at Rs 5.06/ha cm	248.94	97.97	165.22
ii) Water at Rs 9.02/ha cm	248.90	97.60	164.71
iii) Water at Rs 24.86/ha cm	248.61	96.11	162.64
D. *Brin/af at Rs. 1.20/kg and nitrogen at Rs 6.11/kg*			
i) Water at Rs 5.06/ha cm	248.92	97.89	164.69
ii) Water at Rs 9.02/ha cm	248.87	97.52	164.17
iii) Water at Rs 24.86/ha cm	248.57	96.03	162.11

$MP_N = 37.9516 - 1.1596\,N + 1.6066\,W$.] The marginal productivity curves are linear and decreasing because of quadratic form of the production function. The rate of decrease of marginal product for each additional unit was 11.0226 and 1.1596kg for water and nitrogen respectively. This shows that each additional unit of water for a given level of nitrogen decreases yield more rapidly than the nitrogen for a given level of water.

Marginal rate of substitution:

To know the extent to which water and nitrogen can be substituted in the production process, the rate of substitution was worked out for yield levels of 5,000 10,000, 15,000, 20,000 kg/ha and presented in Table 2. It could be observed from the table that the choice of combination of water and nitrogen was more at lower levels of production as compared to higher levels. For producing 20,000 kg/ha the choice was limited to either 75 kg of nitrogen and 74 cm of water or 100 kg of nitrogen and 67 cm of water per hectare whereas for producing 5,000 to 10,000kg/ha the choice was between 0 kg nitrogen and 40 cm of water to 75 kg nitrogen and

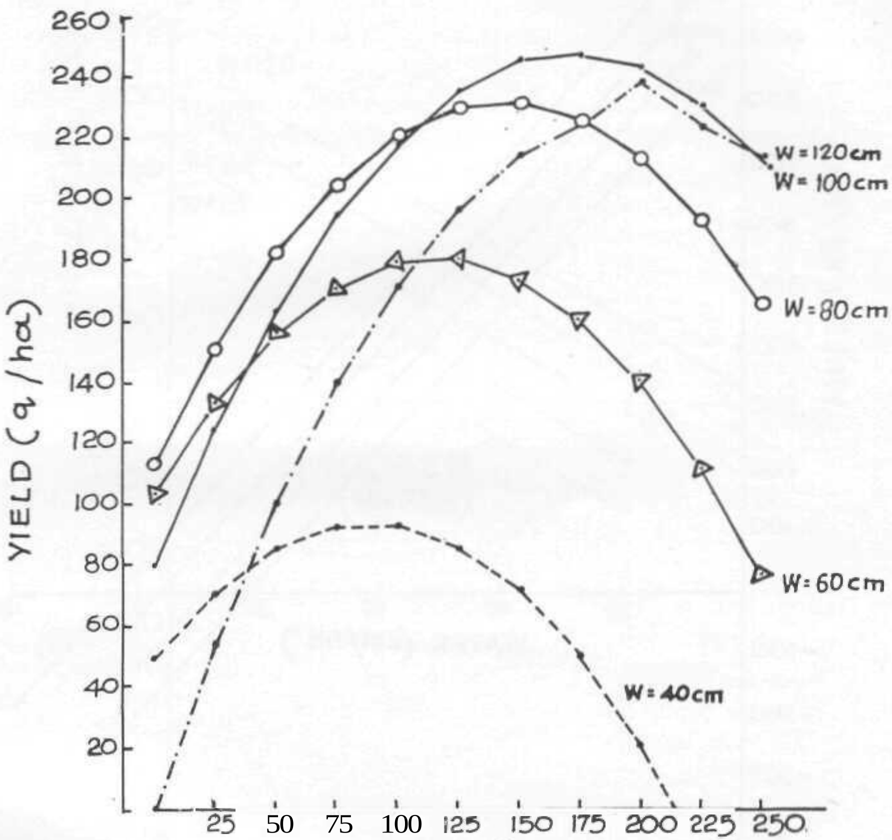

Fig-1

Brinjal yield response curves to nitrogen at specified levels of water

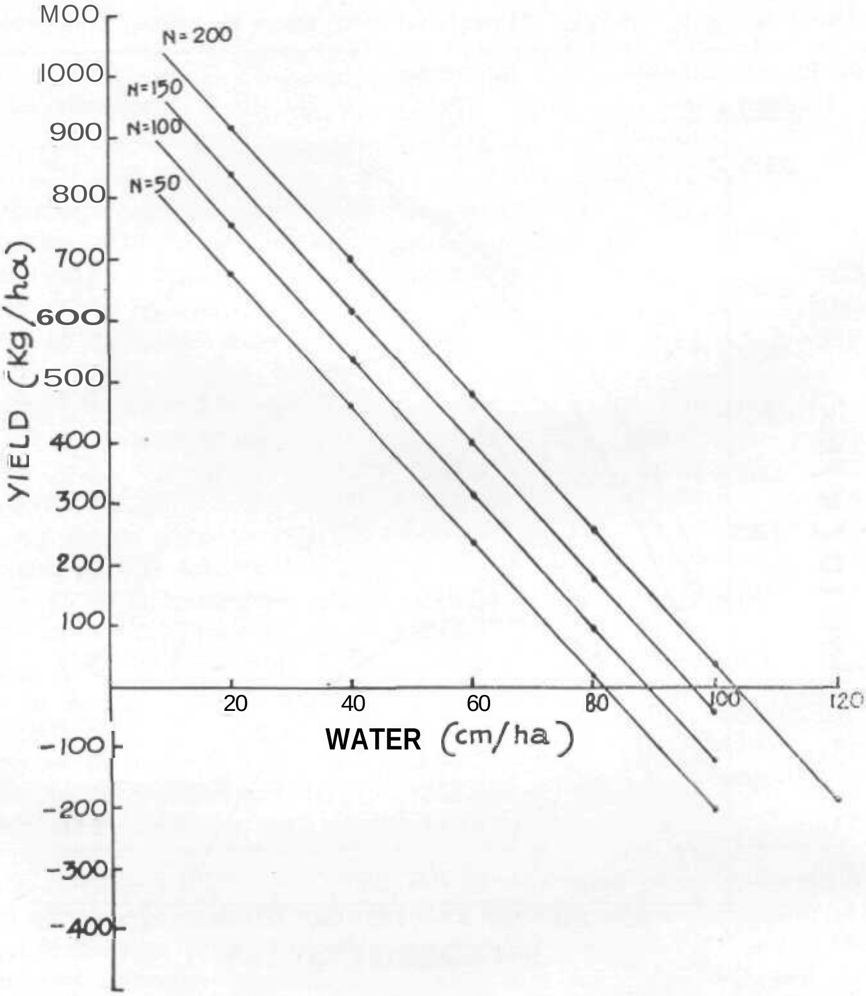

Fig. 2.

Marginal product curves for water in production of brinjal at specified levels of nitrogen

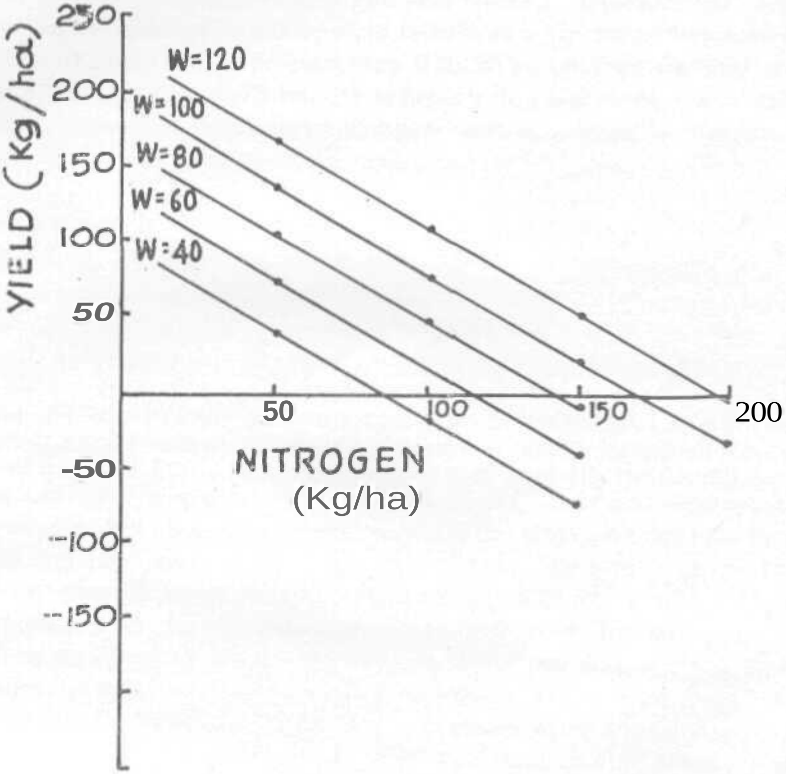

Fig. 3.

Marginal product curves for nitrogen in production of brinjal at specified levels of water

32 cm of water. It could also be observed that for achieving higher levels of production both the inputs are needed, whereas lower levels of production can be achieved even with the use of one input only. The marginal rate of substitution between nitrogen and water was also very low and decreasing rapidly. For example the reduction in use of water at 5,000 kg yield level was 5 cm for an increase of 25 kg nitrogen when nitrogen was increased from 0 to 25 kg per hectare and as nitrogen use was increased from 50 to 75 kg, the reduction in quantity of water was hardly 0.8 cm. This shows that water and nitrogen are substitutable to a very limited extent in the production process.

Economically optimum levels of water and nitrogen :

The fitted equation was tested for satisfying the conditions for existence of maximum. The first order and second order conditions for existence of maximum are (i) $\partial y/\partial w = \partial y/\partial n = 0$ (ii) $\partial^2 y/\partial w^2, \partial^2 y/\partial N^2 < 0$ and (iii) $\partial^2 y/\partial w^2 \, \partial^2 y/\partial N^2 > (\partial V \; \partial w \, \partial n)^2$ respectively (Chliang, 1974).

The results based on the optimization are presented in Table 3. The optimum combination of inputs was examined for three water prices (basad on the source of irrigation and mode of lifting representing tube well with electric pump, open well with charsa and canal with persian wheel as given in Balister and Rosan Singh, 1979) and two products and nitrogen price situations. (The nitrogen prices are those prevailing in 1980 and 1981 and based on the price of urea. The results showed that there was not much change either in optimum combination of inputs or yield in different price situations. Even though water price was increased by 390 per cent i. e., from Rs 5.6 to Rs 24.86/ha cm the reduction in water use was hardly 2 to 4 percent under different nitrogen and product price situations. There was only very slight reduction (around 0.7 per cent) in the use of nitrogen when the price of nitrogen was increased from Rs 4.52 to Rs 5.11/kg. The optimum output was also around 248 q/ha even though price of output was doubled from Rs 0.60 to 1.20 kg. This clearly shows that the price of water, nitrogen and product did not have much effect on the optimum combination of these sources in the production process.

Summary

A quadratic type of production function was fitted to yield-water-nitrogen data obtained from an experiment conducted on brinjal in summer 1977 at the experimental station of the Indian Institute of Horticultural Research, Ressaraghatta. The use of response function has shown that nitrogen and water are substitutable to some extent in the production process. However, the range of substitutability was very limited and both the inputs have to be usad at higher levels of production. The sensitivity analysis has shown that the optimum combination of water and nitrogen seems to remain stable over a wide range of input and output prices. The water usage and hence the demand for water was mostly dependent on the nitrogen us rather than price of water.

സംഗ്രഹം

വഴുതനയുൽപാദനം ജലം, പാക്യജനകം എന്നിവയുടെ അളവുമായി ഒരു ദ്വിഘാത ഫലനം മൂലം ബന്ധപ്പെടുത്താം. ഈ ഫലനത്തിൽ ഉൽപാദനം കണ്ടുപിടിക്കുന്നതിന് ജലവും പാക്യജനകവും ഒരു പരിധിവരെ പരസ്പരം മാററി ഉപയോഗിക്കാവുന്നതാണ്. വർദ്ധിച്ച ഉൽപാദനാവസ്ഥയിൽ രണ്ടു നിവേശങ്ങളുടെ അളവും വെവ്വേറെ ഉപയോഗിക്കേണ്ടിവരുന്നു. നിവേശ-ഉൽപാദന വിലകളിൽ വരുന്ന വ്യതിയാനങ്ങൾ ജലത്തിൻെറയും പാക്യജനകത്തിൻേറയും അനുയോജ്യമായ സംയോജന നിലവാരത്തിൽ കാര്യമായ മാററം വരുത്തുന്നില്ല. പാക്യജനകത്തിൻെറ ഉപയോഗമാണ് ജലത്തിൻെറ വിലയേക്കാളുപരിയായി ജലത്തിൻെറ ആവശ്യകതയെ നിയന്ത്രിക്കുന്നത്.

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