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Optimization of Irrigation for Potato with Microsprinkler Irrigation System

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ABSTRACT

Water application for agriculture in semi-arid areas should be limited because of scare resources. An effort was made at Central Institute of Post Harvest Engineering and Technology, Abohar to determine the optimal water allocation to potato crop with micro sprinkler irrigation system. In this study, crop production and cost functions for potato were derived from field data and analyzed for determination of amount of water required to attain the maximum yield potential and profit. Results of the study indicated higher yield at I_4 (1.2 Ep) irrigation level, whereas water use efficiency was found to be maximum at I_3 (1.0 Ep). Derived relationship revealed that 280 mm of water (average value of two years) is required to get maximum potato yield with microsprinkler irrigation system under semi arid environment. Further, present study clearly indicated that reduction in water application from 280 mm (water level for maximum yield) to 247 mm (water level for maximum profit) increased net profit by 7%. When land is not a constraint, the saved water could be used to bring 12% more area under irrigation with micro sprinkler irrigation system to enhance the farmer's income.

Potato is a popular crop throughout the world. Presently world production is about 322 million tonnes fresh tubers from an area of 18.96 million ha. In India, the area under the crop has increased from 0.6 million hectares in 1980 to 1.3 million ha in 2005 and production has increased from11.88 to 23.63 million tonnes. Potato is relatively sensitive to soil moisture stress because it has a sparse root system and approximately 85% root length is concentrated in the upper 0.3 m soil layer (Opena and Porter, 1999). Water stress during the critical growth period delays the growth resulting in to a reduction in crop yield due to smaller plant leaf canopy and reduction in biomass production.

The ideal conditions for potato growth include high and nearly constant soil matric potential, high soil oxygen diffusion rate and optimal nutrient. Thus, maximum profit from potato cultivation requires minimum fluctuation in soil moisture content within the root zone. Hence, timing and amount of irrigation for potato should be such that fluctuation in soil water is minimum through out the growing season. Further, in arid and semi-arid regions where winters are very cold, microsprinkler irrigation system with appropriate irrigation schedule may play a vital role in potato production as it is considered to modify the climatic conditions up to some extent (Spieler, 1994). Under these conditions, it is necessary to develop efficient and reliable irrigation management strategies for successful potato cultivation. This study was undertaken with the objective to generate the field data and derive the equations for determination of irrigation water leading to maximum crop yield or profit with limited water.

MATHEMATICAL FORMULATION

Potato tuber yield, $Y(w)$, is a function of amount of water applied. Cost function, $C(w)$, can be determined from the summation of cost incurred in agronomical practices like field preparation, labour and energy required for various farm operations along with the investment required for adoption in microsprinkler irrigation system. It includes cost of system components and water development charges i.e. storage tank to store canal water supply for ensuring water supply for microirrigation in canal irrigated area where ground water is not suitable for agriculture.

The net income is dependent on application of water and nitrogen and irrigated area as follows:

$$I = A \times i(w) \qquad ...(1)$$

where I is the total net income, A the irrigated area and i

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(w) the net income per unit area. *i(w)* is a function of applied water as follows

$$i(w) = P \times Y(w) - C(w) \qquad ...(2)$$

where *P* is the price of unit weight of produce. The irrigated area may also be a function of water use. If the water is limited, the farm manager may put enough land under irrigation to just exhaust his water supply. The irrigated area will be then

$$A = \frac{w_t}{w} \qquad ...(3)$$

where w_t is total available water supply and w is applied water depth.

The value of *w* that can maximize the crop yield (w_m) can be determined by taking derivative of the yield function as follows

$$\frac{\partial Y(w)}{\partial w} = 0 \qquad ...(4)$$

The values of *w* that satisfy the above equations are w_m.

To determine the amount of water that will maximize net income, take the partial derivative of Eq. (1) with respect to *w* and setting it equal to zero.

$$\frac{\partial I}{\partial w} = A\frac{\partial i(w)}{\partial w} + i(w)\frac{\partial A}{\partial w} = 0 \qquad ...(5)$$

When water is limited, A is a function of w , as was noted. The optimum water can be determined from Eq. (5). The derivative of Eq. (2) and (3) can be written as

$$\frac{\partial i(w)}{\partial w} = P\frac{\partial Y(w)}{\partial w} - \frac{\partial C(w)}{\partial w} \qquad ...(6)$$

$$\frac{\partial A}{\partial w} = -\frac{w_t}{w^2} \qquad ...(7)$$

By substituting Eq. (2), (6) and (7) in (5)

$$w[P\frac{\partial Y(w)}{\partial w} - \frac{\partial C(w)}{\partial w}] = PY(w) - C(w) \qquad ...(8)$$

For the particular case of the yield and cost function which can be represented by the following equations

$$Y(w) = a_0 + a_1 w + a_2 w^2 \qquad ...(9)$$

$$C(w) = c_0 + c_1 w \qquad ...(10)$$

where a_0, a_1, a_2, c_0 and c_1 are constants. Eq. (9) is an approximation of the true response of potato yields to seasonal water applied. Using Eq. (8), (9) and (10), the values of seasonal water application can be determined which is required for maximization of yield and net income when water is limiting. The two level of water use can then be shown to be

$$w_m = -\frac{a_1}{2a_2} \qquad ...(11)$$

$$w_w = \left[\frac{Pa_0 - c_0}{Pa_2}\right]^{1/2} \qquad ...(12)$$

SITE AND EXPERIMENTAL DETAILS

The experiment was conducted at the research farm of Central Institute of Post Harvest Engineering and Technology, Abohar (30^0, 09' N, 74^0, 13' E and altitude of 186 m above sea level) from October to January in 2003-2005. The soil was sandy loam with pH of 8.48. The available N, P and K in top 30 cm soil was 58.80, 12.5 and 281.4 kg/ha, respectively. The bulk density of soil for 0-0.15 and 0.15-0.30 m depth was 1.55 and 1.57 g/cc, respectively. The soil moisture content in the 0-30 cm soil layer was 17.81 cm/m and 6.11 cm/m at field capacity and wilting point, respectively and plant available water was 11.7 cm/m.

The experiment was laid out in randomized block design (RBD). The plot size was 36 m^2 (6 x 6 m). A buffer zone spacing of 1.0 m was provided between the plots. Farm yard manure (FYM) @ 50 t/ha was applied prior to the field preparation. Water soluble fertilizer @ 187 kg/ha N; 63 kg/ha P_2O_5 and 125 kg/ha K_2O (recommended dose of nutrient) was applied through fertigation. Potato tubers of Cv. Kufri Chandramukhi were planted at 60 x 10 cm spacing in the month of October. Immediately after planting, furrow irrigation was given to each plot for better germination and crop establishment. The differential microsprinkler irrigation treatment was started after two weeks of planting. During the entire course of study, micro-jet type microsprinklers (discharge rate 64.8

lph) was operated at 1.20 kg/cm^2 pressure and approximately 10.50 mm water was applied in each irrigation. On the basis of pan evaporation (Ep), 0.6 (I_1), 0.8 (I_2), 1.0 (I_3) and 1.2 (I_4) times of pan evaporation (Ep) were used as irrigation levels for irrigating the experimental crops. Ep was computed as sum of daily evaporation of United State Weather Bureau (USWB) - Class-A open pan located adjacent to the experimental field with moderate grass cover. Water-soluble fertilizers were used to supply the required nutrient to the crop through fertigation. Venturi was used to inject the nutrient solution in the pipeline. Matured crop was harvested at 85-90 days after planting for estimating the yield. Irrigation water use efficiency was calculated as the ratio of total crop yield to irrigation water applied (Imtiyaz *et al.*, 2000).

RESULTS AND DISCUSSION

Yield and Water Use Efficiency

Yield and water use efficiency of potato observed for different irrigation treatments are presented in Table 1. It is evident from the data that potato tuber yield increased with the increase in amount of water application under different irrigation treatments. The variation in yield between the crop growing seasons was recorded due to variation in climatic conditions, but the trend of increase in tuber yield with different irrigation treatments was almost similar. Highest yield was recorded with the highest water application (treatment I_4) because of higher number of larger size of potato tuber amongst other irrigation treatments, but yield reduction in I_2 was found non-significant. However, when irrigation was scheduled at I_3 (0.80 Ep) or below, the tuber yield reduced significantly. This was probably due to the fact that soil moisture depleted to such extent that extraction of water by the roots was affected. Kumar *et al.* (2006) also reported significant reduction in drip irrigated potato yield with the decrease in irrigation water.

Higher irrigation water use efficiency of 1.37 q/ha-cm (average of two years) was observed in I_3 (Table 1) among all treatments, whereas lowest IWUE (1.21 q/ha-cm) was recorded with I_1. It can be concluded from the study that water was used most efficiently in I_3 level of irrigation under microsprinkler irrigation regime. Kumar *et al.* (2007) also reported similar variation in water use efficiency with microsprinkler irrigation system for onion. Hence, under water limiting situation, I_3 (1.0 Ep) would be the most appropriate level for cultivating potato with microsprinkler irrigation system.

Optimization of Water Application

Fig.1 depicts the revenue and cost functions for potato cultivation under microsprinkler regime. The revenue function is shown as curved line, while straight line is simple cost function. Intercept of these two lines represents the fixed cost and slope represents the operating cost. Vertical differences between these two lines show the profit.

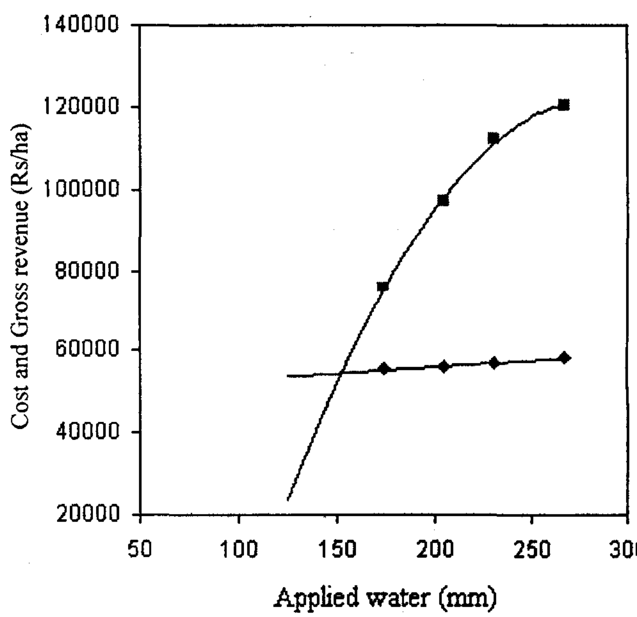

Fig. 1: Revenue and cost functions for potato cultivation

Table 1. Crop yield, water applied and water use efficiency measured for different irrigation treatments

Irrigation treatment	Water applied (mm)	Yield (q/ha)	Water use efficiency (q/ha-mm)	Water applied (mm)	Yield (q/ha)	Water use efficiency (q/ha-mm)	Average yield (q/ha)	Average water use efficiency (q/ha-mm)
		1st year			2nd year			
I_1 (0.6 Ep)	174	213.0	1.22	162	191.0	1.18	202.0	1.20
I_2 (0.8 Ep)	205	273.0	1.33	181	250.5	1.38	261.8	1.36
I_3 (1.0 Ep)	231	316.5	1.37	199	271.0	1.36	293.7	1.37
I_4 (1.2 Ep)	267	339.0	1.27	218	293.0	1.34	316.0	1.31

Production function was obtained by regression analysis as with values for the coefficient of determination (0.90), standard error (SE) of 1.45, where y(w) is potato yield (t /ha), w is the irrigation water applied (mm). The relationship between production cost per ha and seasonal water applied and net revenue and seasonal water applied are presented in Figs. 2 and 3. Linear cost functions and curvilinear net revenue functions were derived from these figures. Crop price was Rs.355 and 362 per ton in 1st and 2nd season, respectively while production cost varied from 55,000 to 58,000 Rs/ha for the different crop growing years. Production cost

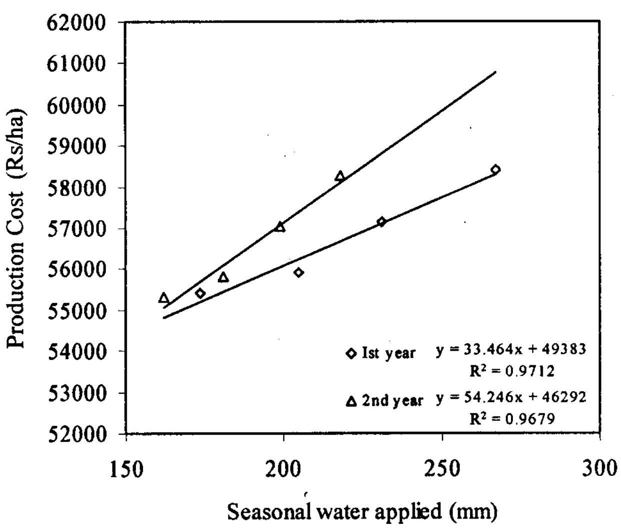

Fig. 2: Relationship between production cost and seasonal water applied in different crop growing season

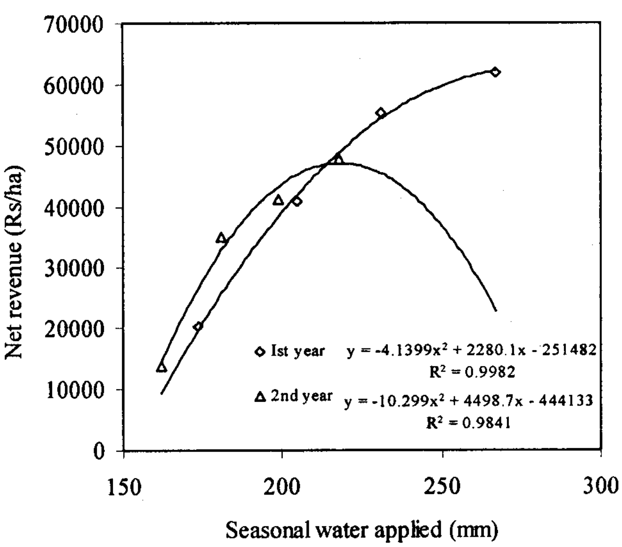

Fig. 3: Relationship between net revenue and seasonal water applied in different crop growing season

varied with the treatments due to variation in operating cost like water and energy price, harvesting and transportation cost etc.

Analysis of observed production functions revealed that approximately 317 and 220 mm irrigation water is required for maximizing the yield of potato with microsprinkler irrigation system in the 1st and 2nd season, respectively, while the amount of water application to maximize the economic return where water is limiting was found to be 275 and 218 mm. About 12% reduction in irrigation water from w_m (water level for yield maximization) to w_l (water level for profit maximization) increased the profit by about 7% with the unit volume of water.

CONCLUSIONS

Results of the study indicated that variable irrigation levels had significant influence on potato yield and water use efficiency under microsprinkler irrigation regime. The highest potato yield was recorded in I_4 (1.2 Ep) irrigation level whereas water use efficiency was found to be highest under I_3 (1.0 Ep) irrigation level. The study indicated that I_3 would be most appropriate irrigation level to produce potato with microsprinkler irrigation system under limiting water situation. Derived equations also suggested that microsprinkler irrigated crop required 247 mm of water for maximizing the profit.

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