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Rice Optimal Water Use in Different Air Temperatures at Flowering, Nitrogen Rates and Plant Populations

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Abstract: Present study was conducted to determine optimal amounts of irrigation water for rice in different nitrogen application rates, flowering stage air temperatures, T_f and plant populations. The results indicated that in water limiting conditions in the study area, the optimum irrigation water was affected by crop management (N application rate and plant population) and climatological factors such as T_f. The optimum amounts of water, w_w decreased at a higher rate (from 1988 to 1226 mm) by increase in nitrogen application rate (from 0 to 150 kg N ha^{-1}) at higher T_f and plant population. These values were 2692 to 2191 mm of water for 0 to 150 kg N ha^{-1} for low value of T_f and plant population. Under unfavorable air temperature condition and low plant population, the w_w decreased by 19% at 150 kg N ha^{-1}, compared with 0 kg N ha^{-1}. However, under favorable air temperature condition and high plant population, this value was 38%. Therefore, under water limiting conditions in the study area, the higher plant population and favorable climatological factor can highly reduce the optimum irrigation water at higher N application rate. Also, N application rate, plant population, P, air temperature at the flowering stage and applied irrigation water affected the net income. The maximum net income was obtained in T_f = 28.2°C (near optimum air temperature during the flowering stage, 30-33°C), P = 25 hills m^{-2}, 120 kg ha^{-1} N application and 2138 mm applied irrigation water. The field management factors such as applied irrigation water, nitrogen application rate and plant population can be controlled by field manager and the optimum amounts may be applied. However, the climatological factors are unpredictable, therefore, these factors should be considered in economic analysis of crop yield production and field management.

Key words: Irrigation water, nitrogen, flowering stage air temperatures, rice

INTRODUCTION

Deficit irrigation is an optimizing strategy under which crops are deliberately allowed to sustain some degree of water deficit and yield reduction. The fundamental goal of deficit irrigation is to increase Water Use Efficiency (WUE) or Water Productivity (WP), either by reducing irrigation adequacy or by eliminating the least productive irrigation. It is widely recognized that when water supplies are limited or water costs are high, the economic optimum level of irrigation will be something less than would be required for maximum yield. Where there are constraints on capital, energy, labor or other essential resources, or when costs of any of these resources are particularly high, deficit irrigation can be used as a strategy to increase profits. This approach can also be used to maximize profits or stabilise regional crop production (Tavakoli and Oweis, 2004). Deficit irrigation is not without controversy, but if the objective is to maximise profits or stabilise food production it is a valid and useful strategy (Sepaskhah *et al*., 2006). This new concept of irrigation scheduling has different names, such as regulated deficit irrigation, pre-planned deficit evapotranspiration and deficit irrigation (English *et al*., 1990).

Optimal allocation of irrigation water and nitrogen fertilizer is very important for agricultural purpose, especially in arid regions or regions where contaminated water is a prime concern in agriculture (Trimmer, 1990; English and Raja, 1996; Godwin and Jones, 1991; Weinhold *et al*., 1995; Zand-Parsa and Sepaskhah, 2001).

Nitrogen is currently the most widely used fertilizer nutrient and the demand for it is likely to grow in future (Godwin and Jones, 1991). Nitrogen is a component of protein and nucleic acid and when nitrogen amount in soil is not optimal, growth is reduced (Weinhold *et al*., 1995). Nitrate-N is highly soluble in water and hence susceptible to leaching, potentially contributing to environmental contamination. Also, fertilizer N can be lost via

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denitrification, especially from moist soils. Denitrification losses reduced the N fertilizer use efficiency and are environmental concern for the potential role of N_2O that it may play in stratospheric ozone depletion (Qian *et al.*, 1997).

The different amounts of water and nitrogen application were used for corn (Peng and Letey, 1998) and rice (Pirmoradian *et al.*, 2004a, b). They showed that the larger amount of irrigation water, provided larger amount of deep percolation, which resulted in much nitrogen leaching and less yield.

The amounts of applied water and nitrogen for the maximum yield of corn, the maximum profits at the limiting land and water conditions are determined by Zan-Parsa and Sepaskhah (2001). In this study the optimum applied water and nitrogen application rate in land limiting conditions were 0.99 m and 212 kg N ha^{-1}, respectively. These values in water limiting condition were obtained 0.736 m and 206 kg N ha^{-1}, respectively. The results of similar analysis were reported by Sepaskhah *et al.* (2006) for winter wheat.

This study was conducted to determine optimal irrigation water use for rice in different nitrogen application rates, flowering stage air temperatures and plant populations.

MATERIALS AND METHODS

Conceptual model: A gross income curve is represented. The level of irrigation that would maximise yield is shown as w_m in Fig. 1. The straight line in Fig. 1 represents a cost function relating total production costs to applied water. In this Figure the w_m is the amount of water for maximum yield and w_l is the optimum water for land limiting condition. At the point of w_{el} the net income per unit of land will just equal the net income from full irrigation. The point of w_w is the optimum water for water limiting condition. Under this condition, at the point of w_{ew} the net income per unit of land will just equal the net income from full irrigation.

It is possible to derive a set of equations to estimate the values of the aforementioned variables (w_m, w_l, w_w, w_{el}, w_{ew}). Such equations would be useful for analysis of optimum water use and irrigation water planning (Sepskhah *et al.*, 2006).

Mathematical formulation: The detail mathematical formulation of deficit irrigation was presented by English *et al.* (1990) and Sepaskhah *et al.* (2006) based on the production and cost functions as follows:

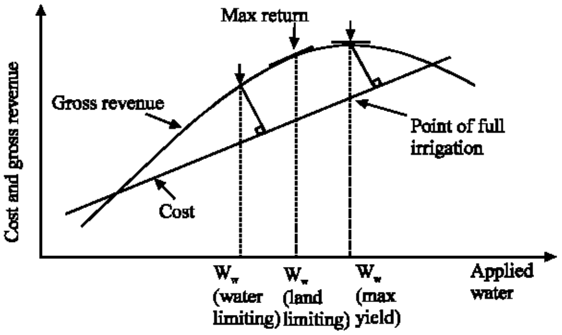

Fig. 1: Revenue and cost functions

$$y(w) = a_1 + b_1 w + c_1 w^2 \tag{1}$$

$$c(w) = a_2 + b_2 w \tag{2}$$

where, a_1, b_1, c_1, a_2 and b_2 are constants. The various levels of water use of interest to the analyst (w_l, w_w, w_m, w_{el}, w_{ew}) were derived by English *et al.* (1990) and Sepaskhah *et al.* (2006) as follows:

$$w_m = -\frac{b_1}{2c_1} \tag{3}$$

$$w_{el} = \frac{b_2 - P_c b_1 + Z_1}{2P_c c_1} \tag{4}$$

$$w_{ew} = \frac{-Z_2 + [Z_2{}^2 - 4P_c c_1 (P_c a_1 - a_2)]^{0.5}}{2P_c c_1} \tag{5}$$

$$w_1 = \frac{b_2 - P_c b_1}{2P_c c_1} \tag{6}$$

$$w_w = \left[\frac{P_c a_1 - a_2}{P_c c_1}\right]^{0.5} \tag{7}$$

where:

$$Z_1 = \left[(P_c b_1 - b_2)^2 - 4P_c c_1 \left(\frac{P_c b_1{}^2}{4c_1} - \frac{b_1 b_2}{2c_1}\right)\right]^{0.5} \tag{8}$$

$$Z_2 = \frac{P_c b_1{}^2 - 4a_2 c_1 + 4P_c a_1 c_1}{2b_1} \tag{9}$$

Site description: This research was conducted at Kooshkak Agricultural Research Station, of Shiraz

University in Islamic Republic (I.R.) of Iran (Lat. 30°7′ N; Long. 52°34′ E; elevation of 1650 m) during the two consecutive growing seasons of 2000 and 2001. The experimental site was placed in the irrigated area of Doroodzan Irrigation District located at south of I.R. of Iran. But the same spot of the Experiment Station Farm was not used in growing seasons of 2000 and 2001; however, the same experimental layout was used in both years. The soil of experimental site was a fine, Carbonatic, mesic, Aquic Calcixerepts soil with pH of 6.9-7.1 (Table 1). Maximum temperatures during the growing season (July-October) ranged from 23 to 39°C in 2000 and from 28 to 40°C in 2001, while the minimum temperature ranged from 7 to 24°C in 2000 and from 8 to 27°C in 2001, respectively. The mean daily maximum and minimum temperatures during the growing season (July-October) are 32.8 and 13.2 in 2000, respectively. These values are 35.4 and 16.2°C in 2001, respectively. Reference crop potential evapotranspirations (ET_o) during the growing period for 2000 and 2001 determined based on FAO-Penman method (Doorenbos and Pruitt, 1977) and were 578 and 650 mm, respectively. These may be converted to potential crop evapotanspiration (ET_p) by multiplying with crop coefficient (K_c). To these the water loss by wind and evaporation should be added. There was no rainfall during the growing season in either year.

Experimental details: The experiment was conducted using 4 replications in a split plot design with irrigation method as main plots and N levels as subplots. Main plots consisted of 5 irrigation regimes: (1) sprinkler irrigation with applied water equal to ET_p, (2) sprinkler irrigation with applied water equal to $1.5ET_p$, (3) continuous flooding irrigation, (4) intermittent flooding irrigation with 1 day interval and (5) intermittent flooding irrigation with 2 days interval. Subplots were composed of three levels of 32, 72 and 112 kg N ha^{-1} for 2000 and 32, 92 and 152 kg N ha^{-1} for 2001 applied as urea and ammonium phosphate. The ammonium phosphate at a rate of 200 kg ha^{-1} was applied before transplanting (32 kg N ha^{-1}). Subplots were 3×3 m basins enclosed by 50 cm bunds. The land was prepared on 8 to 10 July in 2000 and 28 to 30 June in 2001. The experimental plots were separated after the plowed land was saturated and puddled by a tiller. A local cultivar (Champa-Kamphiroozi) of rice seedlings with low tillering ability were transplanted with 16 and 25 hills per unit area m^2 for 2000 and 2001 on 11 and 1 July in 2000 and 2001, respectively. The transplants were about 40 days old. Before transplanting, 200 kg P ha^{-1} was applied as ammonium phosphate. For first 10 days, all of the treatments were irrigated with continuous flooding to establish the seedlings. The applied water in this period was 142 and 166 mm in the years of 2000 and 2001, respectively.

Table 1: Some of the soil properties for experimental site

	Depth (cm)	
Soil properties	0-30	30-60
Sand (%)	30.00	25.00
Silt (%)	39.00	32.00
Clay (%)	31.00	43.00
EC (S m^{-1})	0.14	0.11
pH	7.10	6.90
$N\text{-}NO_3$ (kg ha^{-1})	12.80	10.70
$N\text{-}NH_4$ (kg ha^{-1})	3.30	4.20
P (kg ha^{-1})	17.80	10.90

Four sprinklers with a capacity of 0.5 L sec^{-1} were placed on the corner of each plot of sprinkler irrigation treatments on a riser with 1.0 m height. For sprinkler treatments, the applied water for each irrigation was obtained by the mean of ET_p for 3 pervious days plus evaporation from droplet from the air and wind drift losses of the sprinklers. Evaporation and wind drift losses were determined by measuring the water collected in 45 cans placed in each replication of the experimental plots during water application period. The difference between applied water and collected water in cans was considered as evaporation and wind drift losses. Due to strong wind at daytime and high day temperature, the mean value of this loss was 28.8% in the growing season. For flooding treatments, the water depth in plots was maintained at 5 to 10 cm in irrigation period. For surface irrigation treatments, the water was distributed by pipe to each plot. Therefore, there was no effect of water flow from canals to the plots of surface irrigation treatments. The weed populations were higher in the sprinkler and intermittent flood irrigation treatments. The weeds were removed by hand weeding. In intermittent irrigation treatments, the standing water depths on the plots disappeared after about 24 h and the plots irrigated again before their surface were cracked. Volumetric water meters were used to measure the volume of the delivered water for every main plot in four replications.

Ten days after transplanting, one half of N requirements for different treatments (as urea) i.e., 20 and 40 kg N ha^{-1} for year of 2000 and 30 and 60 kg N ha^{-1} for year of 2001 and irrigation treatments were applied. The remaining N was applied at 40 and 50 days after transplanting (before flowering stage) for 2000 and 2001 years, respectively. During the growing season weeds were controlled by hand weeding. The crop was harvested manually on 8 and 13 October in 2000 and 2001, respectively.

At the end of growing season, yield samples were harvested from 1×1 m area at the middle of plots. Samples were air dried for 5 days before being oven dried at 70°C for 48 h. Then, grain yield was determined. The grain yield and applied water were used to derive the water production function. The revenue per unit area (ha) was calculated by multiplying the produced grain yield (kg ha^{-1}) by price of unit grain weight (€ kg^{-1}). The fixed cost [a_2 in Eq. 2] was calculated by summing the land rent, land preparation, fertilizer (except nitrogen), planting, cropping activities and harvest costs for unit area (ha). The variable cost [b_2 in Eq. 2] was calculated by multiplying the amounts of applied water and nitrogen per unit area (ha) by their unit prices.

RESULTS AND DISCUSSION

Production function: The production function of rice grain yield was obtained by multiple regression analysis as follow:

$$Y = -7361.28 + 9.73N_a + 2.48w - 0.00058w^2 + 229.77T_f + 101.95P \quad (10)$$

where:

Y = Grain yield in kg ha^{-1}.
N_a = Nitrogen application rate in kg ha^{-1}.
W = The seasonal amount of applied irrigation water in mm.
T_f = Air temperature at flowering stage in °C.
P = Plant population in number of hills per unit area (m^{-2}).

The values of coefficient of determination (R^2), Standard Error (SE) and number of observations were 0.91, 445.6 and 30, respectively. The F-value of this multiple regression equation was significant at $p = 4.74\times10^{-12}$ level of probability. In contradiction to the production function for other crops, i.e., wheat, the nitrogen application does not show a quadratic function (Sepaskhah *et al.*, 2006). This was due to the fact that the highest rate of applied nitrogen was 152 kg ha^{-1} which was not high enough to cause yield reduction at higher nitrogen application rate. The Eq. 10 is valid for N_a up to 152 kg ha^{-1}, air temperature at flowering stage up to 33°C and plant population up to 25 hills per unit area (m^{-2}). The slope of regression line is near to slope of 1:1 line and there is not statistically difference between these lines (Fig. 2).

By comparing Eq. 1 and 10, the coefficients of production function were obtained as follows:

$$a_1 = -7361.28+9.73N_a+229.77T_f+101.95P \quad (11)$$

$$b_1 = 2.48 \quad (12)$$

$$c_1 = -0.00058 \quad (13)$$

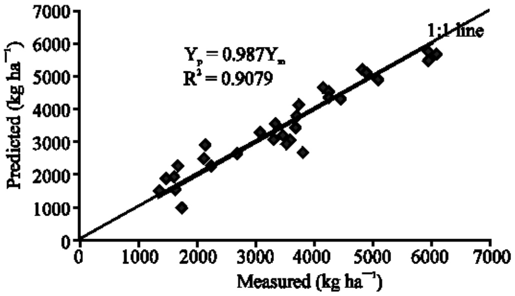

Fig. 2: Relationship between measured (Y_m) and predicted (Y_p) grain yields Eq. 10 for the experimental rice field

where:

a_1, b_1 and c_1 = The coefficients of production function.
N_a = Nitrogen application rate in kg ha^{-1}
T_f = Air temperature at flowering stage in °C
P = Plant population in number of hills per unit area (m^{-2}).

The coefficient of a_1 was obtained for different application rates of N (0, 40, 60, 80 and 120 kg ha^{-1}), air temperatures at flowering stage, T_f (23.9 and 28.2°C) and plant population, P (16 and 25 hills m^{-2}) (Table 2). The revenue was obtained by multiplying grain yield (kg ha^{-1}) by unit price of the grain (0.26 € kg^{-1}).

Production cost function: The coefficients of production cost function a_2 and b_2 (Eq. 2) were determined as follows:

$$a_2 = 1029.32+0.069N_a \quad (14)$$

and

$$b_2 = 0.0055 \quad (15)$$

where:

N_a = Nitrogen application rate in kg ha^{-1}.

The fixed costs (production cost except water and N fertilizer costs) were obtained as 1029.32 € ha^{-1}. The unit price of nitrogen fertilizer was 0.069 € kg^{-1}. The water price was considered as 0.0055 € m^{-3}. The water price was considered for water from a well with 10 m depth that is used in the study area (Table 2). The production cost function is similar to that reported for wheat (Sepaskhah *et al.*, 2006), however, the coefficients are different.

Economic analysis: Using Eq. 3, 4 and 6, the values of w_m, w_l and w_{el}, for two different combinations of air temperatures at flowering stage (23.9 and 28.2°C) and plant populations (16 and 25 hills m^2) were calculated as 2138, 2120 and 2102 mm, respectively. These values were not dependent on the T_f, plant population and N application rates. Similar results were reported by

Table 2: The intercepts of production function [a_1 in Eq. 1] and cost function [a_2 in Eq. 2] for different nitrogen application rated (N), kg ha^{-1} flowering stage air temperature (T_f), °C and plant population (P) (hills m^{-2})

T_f (°C)	P (Hills m^{-2})	N (kg ha^{-1})	a_1	a_2	W_{ew} (mm)	W_w (mm)
23.9	16	0	-245.5	1029.3	2138	2692
		40	143.7	1032.1	2138	2568
		60	338.3	1033.5	2138	2504
		80	532.9	1034.8	2138	2538
		120	922.1	1037.6	2138	2300
		150	1214.0	1039.7	2138	2191
23.9	25	0	672.0	1029.3	2138	2381
		40	1061.0	1032.1	2138	2239
		60	1256.0	1033.5	2138	2165
		80	1450.0	1034.8	2040	2088
		120	1840.0	1037.6	1735	1926
		150	2132.0	1039.7	1506	1794
28.2	16	0	749.4	1029.3	2138	1352
		40	1138.6	1032.1	2138	2209
		60	1333.2	1033.5	2130	2134
		80	1527.8	1034.8	1978	2056
		120	1917.0	1037.6	1672	1891
		150	2208.9	1039.7	1443	1757
28.2	25	0	1667.0	1029.3	1848	1988
		40	2056.2	1032.1	1543	1816
		60	2250.8	1033.5	1390	1724
		80	2445.4	1034.8	1238	1627
		120	2834.6	1037.6	932	1412
		150	2126.5	1039.7	703	1226

Sepaskhah *et al.* (2006). By increasing nitrogen application rate, the optimum amount of water for different flowering stage air temperature and plant population conditions was decreased (Fig. 3). The optimum amounts of water (w_w) decreased at a higher rate (from 1988 to 1226 mm) by increase in nitrogen application rate (from 0 to 150 kg N ha^{-1}) at higher flowering stage air temperatures and plant population. These values were 2692 to 2191 mm of water for 0 to 150 kg N ha^{-1} for low air temperature at flowering stage and plant population. Under unfavorable air temperature condition and low plant population, the w_w and w_{ew} decreased by 19 and 0%, respectively, at 150 kg N ha^{-1}, compared with 0 kg N ha^{-1}. However, under favorable air temperature condition and high plant population, these values were 38 and 62%, respectively. Therefore, under water limiting conditions in the study area, the higher plant population and favorable climatological factor can highly reduce the optimum irrigation water at higher N application rate. However, this result is in contradiction to those obtained for wheat in which w_w increased at higher nitrogen application rate (Sepaskhah *et al.*, 2006). This might be due to the flooding nature of rice plantation.

The net income at any condition was obtained from difference between amounts of revenue and cost. Figure 4 shows that the net income was increased with increasing nitrogen application rate, flowering stage air temperature and plant population. Under unfavorable air temperature condition and low plant population, the net income was negative (Fig. 4a) for all rates of N application and applied irrigation water. Similarly, for unfavorable air

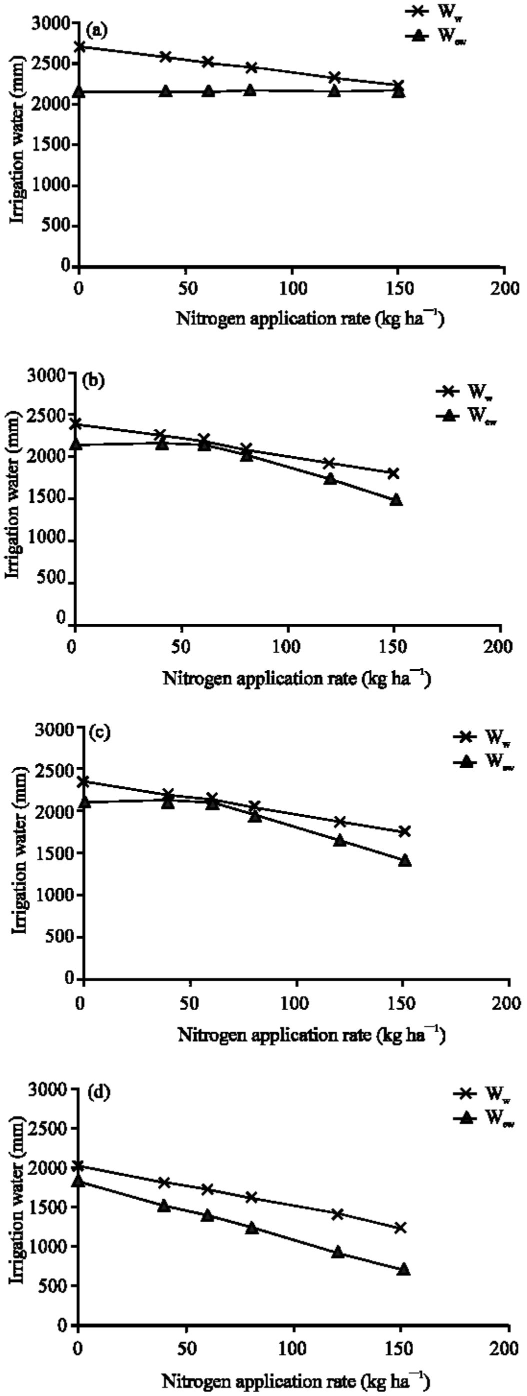

Fig. 3: Variation of W_w and W_{ew} for different nitrogen application rates and irrigation water in different air temperatures at flowering stage (T_f) and plant population (P): (a) for T_f = 23.9°C, P = 16 hills m^{-2}; (b) for T_f = 23.9°C, P = 25 hills m^{-2}; (c) for T_f = 28.2°C, P = 16 hills m^{-2}; (d) for T_f = 28.2°C, P = 25 hills m^{-2}

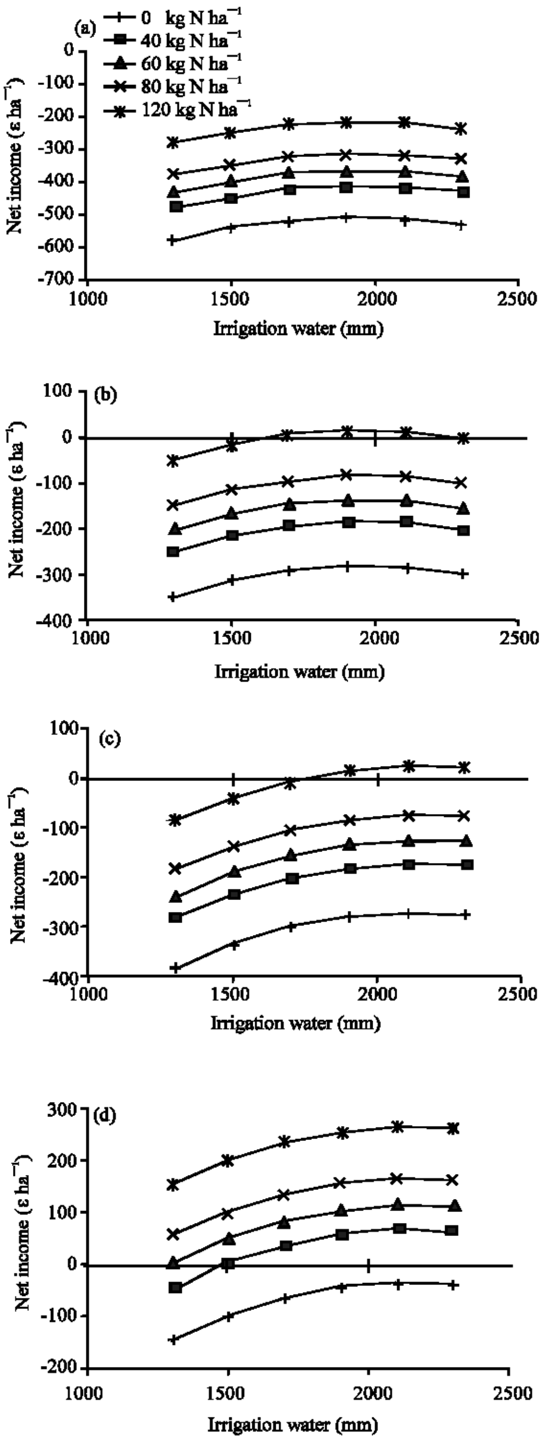

Fig. 4: Variation of net income at different amounts of irrigation water and nitrogen application rates for different air temperatures at flowering stage (T_f) and plant population (P): (a) for T_f = 23.9°C, P = 16 hills m^{-2}; (b) for T_f = 23.9°C, P = 25 hills m^{-2}; (c) for T_f = 28.2°C, P = 16 hills m^{-2}; (d) for T_f = 28.2°C, P = 25 hills m^{-2}

temperature at flowering stage and high plant population the net income was negative except for N application of 120 kg ha^{-1} and applied irrigation water between 1600 to 2300 mm in which a small positive net income was obtained (Fig. 4b). However, as air temperature became favorable, the net income was negative for N application rates of lower than 80 kg ha^{-1} (Fig. 4c), but by application of 1720 mm of water and 120 kg N ha^{-1} positive net income was obtained (Fig. 4c). Furthermore, positive net income was resulted by N application at water application of greater than 1500 mm (Fig. 4d). For a given amount of net income, a lower irrigation water with higher N application rate can be used, i.e., the net income obtained by 80 kg N ha^{-1} and 2300 mm applied irrigation water was similar to that obtained by 120 kg N ha^{-1} and 1300 mm applied irrigation water. Therefore, for a higher net income, one kg ha^{-1} increase in N was equivalent to 25 mm decrease in water. Similarly, zero net income was obtained by 40 kg N ha^{-1} and 1500 mm applied irrigation water and 60 kg N ha^{-1} and 1300 mm applied irrigation water or one kg ha^{-1} of N was equivalent to 10 mm decrease of water (Fig. 4d).

The maximum net income was obtained in T_f = 28.2°C, P = 25 hills m^{-2}, 120 kg ha^{-1} N application and 2138 mm applied irrigation water (Fig. 4d). The optimum and low critical air temperatures during the flowering stage of rice are reported to be 30-33 and 22°C, respectively (Smith and Hamel, 1999). Therefore, the maximum net income was obtained in near optimum air temperature during the flowering stage. Furthermore, it should be noted that all of the effective factors on yield can be affected by the results of economic analysis. Therefore, some of these uncontrollable factors, particularly climatological factor should be considered in economic analysis.

CONCLUSIONS

The results indicated that the optimum irrigation water for maximum yield production (w_m) was 2138 mm. In land limiting conditions, w_l and w_{el} were obtained as 2120 and 2102 mm, respectively. In water limiting conditions in the study area, the optimum irrigation water was affected by field management (N application rate and plant population) and climatological factors such as air temperature at the flowering stage. The optimum amounts of water (w_w) decreased at a higher rate (from 1988 to 1226 mm) by increase in nitrogen application rate (from 0 to 150 kg N ha^{-1}) at higher flowering stage air temperatures and plant population. These values were 2692 to 2191 mm of water for 0 to 150 kg N ha^{-1} for low air temperature at flowering stage and plant population. Under unfavorable air temperature condition and low plant population, the w_w and w_{ew} decreased by 19 and 0%, respectively, at 150 kg N ha^{-1}, compared with 0 kg N ha^{-1}. However, under favorable air temperature condition and high plant population, these values were 38 and 62%, respectively. Therefore, under water limiting conditions in the study area, the higher plant population and favorable climatological factor can highly reduce the optimum irrigation water at higher N application rate.

Also, N application rate, plant population, air temperature at the flowering stage and applied irrigation water affected the net income. The maximum net income was obtained in $T_f = 28.2°C$ (near optimum air temperature during the flowering stage, 30-33°C), P = 25 hills m^{-2}, 120 kg ha^{-1} N application and 2138 mm applied irrigation water. The field management factors such as applied irrigation water, nitrogen application rate and plant population can be controlled by field manager and the optimum amounts may be applied. However, the climatological factors are unpredictable, therefore, these factors should be considered in economic analysis of crop yield production and field management.

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