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Full Length Research Paper

Organization of nitrogen fertilizer, irrigation and plant concentration in onion production using response surface method as optimum approach

Amoon S. Afsaneh, Ramah G. Hatima and Radmehr P. R Arsham

Department of Plant and Crop Science, Faculty of Agriculture, University of Tabriz, East Azarbaijan Province, Iran.

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Response surface methodology (RSM) is defined as a collection of mathematical and statistical methods that are used to optimize a product or a process. In order to determine optimum levels of nitrogen (N), water volume and plant density of onion (*Allium cepa* L.), and field experiment was carried out according to a central composite design as RSM in Azarshahr County, East Azerbaijan Province, Iran –repeated over two years (2011 and 2012). The treatments were designed based on low and high levels of N, irrigation and plant density as independent variables. Furthermore, bulb yield, N losses, N uses efficiency (NUE) and water use efficiency (WUE) were measured as response variables in a full quadratic polynomial model. Optimum rates of N, irrigation and plant density was suggested to achieve the target range of response variables based on three scenarios: Economic, environmental and eco-environmental. The results showed that increasing of N fertilizer up to 160 kg N ha^{-1} led to increase in bulb yield. The amounts of 93.48 kg N ha^{-1}, 8930 m^{3} water ha^{-1} and 42.67 onions m^{-2} was found to be the optimum conditions for eco-environmental scenario. In general, it seems that resource use based on eco-environmental scenario may be the most favorable cropping strategy in onion production.

Key words: Environment N losses, N uses efficiency (NUE), water use efficiency (WUE).

INTRODUCTION

Onion is one of the most important vegetable crops in East-Azerbaijan Province of Iran with a cultivation area and production of 6074 ha and average yield of 4014 kg ha^{-1}, respectively (MAJ, 2011). Most of bulb onion production belongs to East Azerbaijan province with an annual production of approximately 500×10^{3} tons. High rates of N fertilizer are usually applied to onion fields in the area to increase overall yield and bulb size, commonly without regard to soil test. The cost of N fertilizer is generally low in Iran; therefore, farmers are not really concerned about the quantity of N application. They often apply N to ensure high yields and large sized onions. Bybordi et al. (2005) reported that N fertilizer was applied up to 1000 kg N ha^{-1} in some areas of the province.

Nitrogen is one of the most important nutrients in crop production systems. Excessive use of N can lead to a declining trend in N use efficiency. It has been reported that not more than 33% of N applied is used by the plant and the remaining is lost and causing environmental pollution such as groundwater pollution and emission of greenhouse gases (Raun and Johnson, 1999). Increasing the NUE of onion through modifications in farming practices would be beneficial in improving the efficiency of fertilizer use, and the sustainability of onion production systems.

Irrigation is an increasingly important practice for sustainable agriculture in Iran. In most regions of the country, irrigation water supplies are mainly from

*Corresponding author. E-mail: Radmehr 216@gmail.com

groundwater sources that are being depleted. As about 85% of water used for irrigation come from non-renewable ground water sources (MAJ, 2011). This share is expected to rise and subsequently decrease the ground-water levels in many regions of Iran. Hence, water consumption for irrigation from ground-water sources has to compete with industries and urban demands (Al-Sulaimi et al., 1996). Irrigation management is important to improve economy and utilize water resources more effectively. Optimum water supply to crops not only has a direct impact on crop yield and water use efficiency but may also improve fertilizer efficiency (Meinke et al., 1997; Banedjschafie et al., 2008).

Irrigation, crop, and N management practices need to be developed to reduce NO_3–N leaching potential and improve NUE. Since rooting depth in onion is shallow (<60 cm), it requires frequent irrigation to obtain high yield as well as maintaining market grade and quality (Schwartz and Bartolo, 1995). A crop yield of 40 tons of bulb yield per hectare was achieved through applying about 110 kg N ha^{-1} (Bybordi et al., 2005). Overall rates of applied N fertilizer and high frequent irrigation contribute to a high NO_3-N leaching potential (Ells et al., 1993).

Many researchers reported that onion yield response to N fertilizer rate depends on farm management practices such as type of N source and cultivar (Bybordi et al., 2005), irrigation water levels (Aminpour and Mousavi, 2006) and plant density (Afsar Manesh and Khodadadi, 2006). N fertilizer and irrigation water are two of the most important factors in crop production which in terms of volume have been increased considerably over the last decades in Iran. Yield of onion responds positively to an increase in the amount of applied water and nitrogen until the optimum level has been reached. Optimization of nitrogen fertilization rate in onion yield can vary with water level and plant density. In Iran, many researchers have studied the optimum N fertilization, water irrigation, and plant density in onion production individually. Bybordi et al. (2005) reported that the bulb yield of onion was increased with increasing N rates. They found that higher levels of N fertilizer had no significant effect on yield. Afsar Manesh and Khodadadi (2006) studied the effect of plant density and N levels on onion yield. They reported that the highest yield was obtained with 67 plant m^2 and at 135 kg N ha^{-1}. Daneshmand et al. (2008) showed that onion yield was improved with increasing irrigation water volume. However, N fertilization, irrigation water and plant density have not been evaluated together in onion production experiments.

To reduce the resource losses and environmental pollutions along with achieving appropriate yield, it is necessary to determine resource (such as N and water) optimum level as well as suitable plant density in the agro-ecosystems. Additionally, there is a complex interaction between N fertilizer and water amounts and crop density. Due to a broad range of treatment combinations, using conventional multifactor experiments for evaluation of the effect and choosing the best treatment combination would be very costly, complicated and time-consuming associating with large experimental error. Hence, the response surface methodology (RSM) has been proposed to determine the influences of individual factors and their interactions. With RSM, the interactions of possible influencing factors on responses can be evaluated with a limited number of experimental runs (Wang et al., 2007). So, the objective of this study was to determine the optimal levels of N fertilizer, irrigation water and plant density in onion production based on the central composite design (CCD) experiments performed in Azarshahr County, East Azerbaijan Province, Iran.

MATERIALS AND METHODS

Response surface methodology (RSM)

In order to achieve the acceptable yield with respect to decreasing environmental pollution, input values should be optimized in accordance to a targeted response. One of the methodologies for obtaining the optimum results is response surface methodology (Aslan, 2007; Kwak, 2005). It is essential that the management practice of farm to be economical for achieving the maximum yield, a significant reduction in environmental pollution, saving both resource and production costs. RSM is a statistical method based on the multivariate non-linear model and can be used for optimization of the resource use (Zulkali et al., 2006; Kalavathy et al., 2009). Furthermore, RSM consists of designing experiments to provide adequate and reliable measurements of the response, developing a mathematical model having the best fit to the data obtained from the experimental design, and determining the optimal value of the independent variables that produces a maximum or minimum response (Montgomery, 2001; Kalavathy et al., 2009). It is also useful for studying the interactions of various parameters affecting the response. RSM examines the responses of several factors by varying them simultaneously with a limited number of experiments. Therefore, RSM is a powerful tool for statistical modelling and optimization of the resources using lesser required number of experimental runs according to the experimental design (Cojocaru and Zakrzewska-Trznadel, 2007; Kalavathy et al., 2009). The response surface can be expressed as follows:

$$y = f(x_1, x_2, \ldots, x_k) \tag{1}$$

Where y is the response variable and x_i is the independent variable.

Experimental layout based on central composite design

An effective alternative to the factorial design is the central composite design (CCD), originally developed by Box and Wilson (1951) and improved upon by Box and Hunter (1957). The CCD gives almost as much information as a three-level factorial with a reduced number of tests (fewer than the full factorial experiment). It also arranges the tests with various combinations of independent variables (Obeng et al., 2005; Aslan, 2007). We employed a CCD for three independent variables to design experiments in which the variance of the predicted response, *Y*, at some points of independent variables, *X*, is only a function of the distance from the

Table 1. Coded and actual levels of independent variables.

Run	Coded level of variable			Actual level of variables		
	(X_1)	(X_2)	(X_3)	N fertilizer (N ha^{-1})	Irrigation (m^3 water ha^{-1})	Density (plant m^{-2})
1	-1	-1	-1	50	8000	25
2	+1	-1	-1	250	8000	25
3	-1	+1	-1	50	10000	25
4	+1	+1	-1	250	10000	25
5	-1	-1	+1	50	8000	75
6	+1	-1	+1	250	8000	75
7	-1	+1	+1	50	10000	75
8	+1	+1	+1	250	10000	75
9	-1	0	0	50	9000	50
10	+1	0	0	250	9000	50
11	0	-1	0	150	8000	50
12	0	+1	0	150	10000	50
13	0	0	-1	150	9000	25
14	0	0	+1	150	9000	75
15	0	0	0	150	9000	50
16	0	0	0	150	9000	50
17	0	0	0	150	9000	50
18	0	0	0	150	9000	50
19	0	0	0	150	9000	50
20	0	0	0	150	9000	50

Table 2. Physical and chemical properties of the soil.

Texture	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	EC (dS m^{-1})	pH	Organic matter (%)
Loamy silt	0.085	16	230	3.1	7.77	0.65

point to the center (Clarke and Kempson, 1997; Kalavathy et al., 2009). The number of runs required for the CCD includes the standard 2^k factorial with its origin at the center, 2^k points fixed axially at a distance from the center to generate the quadratic terms, and replicate runs at the center (r); where k is the number of variables (Aslan, 2007). Replicates of the test at the center are very important as they provide an independent estimate of the experimental error.

Recommended number of tests (replacement for run) at the center for three variables is six (Box and Hunter, 1957; Aslan, 2007). Hence the total number of tests required for the three independent variables is:

$$2^k + 2k + r = 2^3 + (2 \times 3) + 6 = 20 \quad (2)$$

Once the desired ranges of values of the variables was designed by Minitab software ver. 16 based on lowest and highest levels of N fertilizer (50 and 250 kg N ha^{-1}), irrigation (8000 and 10000 m^3 water ha^{-1}) and density (25 and 75 plant m^{-2}), they are coded to lie at ±1 for the factorial points and 0 for the center points (Kalavathy et al., 2009). +1, -1 and 0 are dimensionless coded values of the independent variables which they indicate the highest limit, lowest limit and mean of the highest and lowest limits of the variables, respectively. The experimental design matrix resulted by the CCD shown in Table 1 consists of 20 runs of coded levels expressed as actual values.

Field experiment and measurements

The experiment was performed during the growing seasons of 2011 and 2012 in Azarshahr County, Province of East Azerbaijan, Iran. The Research Station (37°46´N, 45°85´E) is located at about 1468 m a.s.l in the northwest of Iran. The total precipitation and average temperature during the crop growing period for 2011 and 2012 were 157, 163 mm and 19.9 and 19.2°C, respectively (Meteorological Organization of East Azerbaijan Province, 2012). Before sowing, soil samples were taken from 0 to 30 cm depth and physico-chemical characteristics of the field soil were determined (Table 2).

Seeds of Azarshahr onion cultivar were hand sown on March 10 in 3 m × 4 m plots with 20 cm row spacing repeated over two years. Once the seeds were sown, furrow irrigation was applied every 10 days. Urea 46% N fertilizer was applied in split application including one-third as preplant N, one at three-leaf stage and the rest at the five-leaf stage. Irrigation treatments were initiated after planting and adjusted by water counter. The onion fields were totally irrigated 20 times in both years. Amount of water applying each time was calculated based on supplied total volume of water in treatments (8000, 9000 and 10000 m^3 water ha^{-1}). Therefore, the amounts of water used at each time of irrigation treatments were 400, 450 and 500 m^3 water ha^{-1}, respectively. Weed control was done by hand during growth season. Five adjacent plants were randomly sampled from each treatment. The sampled onion plants - were separated into leaves and bulbs for dry matter and N-uptake determinations.

N concentration was measured following the micro-Kjeldahl method (Nelson and Somers, 1973). The onion parts were dried at 60°C to determine dry matter yield. Also, soil N levels were assessed using samples taken from depth of 0 to 30 cm at harvest time. All plants of the middle rows of each plot were hand-harvested on October 1, 2011 and October 2, 2012 to determine bulb yield. N losses in the end of growth season were calculated by Equation 3.

$$N_{loss} = N_{initial} + N_{fertilizer} - N_{plant} - N_{residual} \quad (3)$$

Where N_{loss} is N losses, $N_{initial}$ is the initial soil N content, $N_{fertilizer}$ is the applied N fertilizer (pure N (applied N × 46%), N_{plant} is the amount of plant N at harvesting time and $N_{residual}$ is the soil N at 30 cm depth after harvesting.

NUE and WUE were calculated by Equations (4) and (5):

$$NUE = Y_b / N_{fertilizer} \quad (4)$$

$$E = Y_b / W_{irrigation} \quad (5)$$

Where Y_b is the bulb yield (kg ha^{-1}) and $W_{irrigation}$ is the amount of irrigation water (m^3 water ha^{-1}).

Mathematical modeling

When the response data were obtained from the field experiment, a full quadratic polynomial equation was developed to predict the response as a function of independent variables (Kalavathy et al., 2009). The full quadratic polynomial equation as a response model incorporates (Obeng et al., 2005; Aslan, 2007):

1. Linear terms in each of the variables (x_1, x_2, …, x_n).
2. Squared terms in each of the variables (x_1^2, x_2^2, … , x_n^2).
3. First-order interaction terms for each paired combination (x_1x_2, x_1x_3, … , $x_{n-i}x_n$).
4. The coefficients of the response model (b_1, b_2, … , b_n).
5. The intercept coefficient (b_0).

Thus for the three variables, the response model is:

$$y_i = b_0 + \sum_{i=1}^{3} b_i x_i + \sum_{i=1}^{3} b_{ii} x_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{3} b_{ij} x_i x_j \quad (6)$$

Where y is the predicted response, b_i the linear terms, b_{ii} the squared terms, b_{ij} the interaction terms, x_i and x_j represent the coded independent variables. In this study, a full quadratic polynomial equation was obtained using the uncoded independent variables as such:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 \quad (7)$$

The coefficient of the model for the response was estimated using multiple regression analysis technique included in the RSM (Kalavathy et al., 2009).

Scenarios

To calculate the optimum levels of N fertilizer, plant density and water volume as independent variables, we designed three scenarios (economical, environmental and eco-environmental). In each scenario, some of the responses were considered as a main factor to determine the optimum levels of treatments. We incorporated this information into the optimal solution by setting unequal importance values. Larger values correspond to more important responses while, smaller ones to less important responses. We designed that importance value for main factor in each scenario was 2. So, the importance of main factor was 2 times higher than others indicating that two-fold effect of such factor on determination of optimum levels compared to other factors. Bulb yield of onion and N losses were considered as main factors to determine the optimum levels of treatments under economical and environmental scenarios. In the eco-environmental scenario, the main factor was resource use efficiency (water and N fertilizer). Composite desirability was used to assess how well a combination of input variables satisfies the goals which defined for the responses. Composite desirability is the weighted geometric mean of the individual desirabilities for the responses and evaluates how the settings optimize a set of responses overall. Desirability has a range of zero to one. One represents the ideal case; zero indicates that one or more responses are outside their acceptable targeted rates.

RSM evaluation

The adequacy of the model was tested by analysis of variance (ANOVA). In general, the full quadratic polynomial equation was tested to determine the significance of the model and the components of the model (linear, squared, first-order interaction terms). The quality of the fitted model was judged using determination coefficient (r^2). Another used criterion to test differences between predicted and actual data was 1:1 line. In addition, the lack-of-fit test was used to evaluate the adequate of the fitted model. The lack-of-fit calculations are based on a comparison of the residual sum of squares with the sum of squares due to pure error (F-test). When the calculated *p* value of the F-test is less than 0.05, it is considered as the indication of the significance of lack-of-fit test suggesting the model inadequately fits data.

RESULTS AND DISCUSSION

The variance analysis of the treatments showed the effect of year on the analyzed traits was insignificant (Table 3). Therefore, analysis of variance was used for equality or homogeneity of variance by Bartlett's test. The results of Bartlett's test for year illustrated homogeneity of variances in all traits (p>0.05), therefore, the results of two years were pooled (Table 4).

Fitted model

Details of the ANOVA test for full quadratic polynomial model and components of this equation (linear, squared and First-order interaction) of response variables (bulb yield, N losses, NUE and WUE) are summarized in Table 5. The results of ANOVA test showed that the full quadratic polynomial equation and components of the equation were significant based on F test (-$p < 0.01$) for all of the variables except the first-order interaction term for WUE variable (Table 5). The polynomial models for response variables gave insignificant lock-of-fit test indicating that the data of experiment were adequately fitted by model (Table 5). Determination coefficient of dependent variables included bulb yield, N losses, NUE and WUE were 97.43, 99.61, 99.84 and 98.19% respectively.

Table 3. ANOVA (Mean Square) for the measured traits of onion.

S.O.V	df	Yield	N losses	NUE	WUE
Run	19	174998523**	38.8**	4832.2**	2.13**
Year	1	1294822^{ns}	8.4^{ns}	187.5^{ns}	0.022^{ns}
Error	19	1439715	6.9	121.6	0.018

^{ns} = Non significant; * = Significant at 5% level; ** = Significant at 1% level.

Table 4. Bartlett's test for equal variance of the measured traits of onion versus year.

Parameter	Yield	N losses	NUE	WUE
Chi-square	0.141	0.088	0.091	0.258
p-value*	0.732	0.562	0.610	0.825

*The p-value > 0.05, indicating homogeneity of variance.

Table 5. ANOVA (Mean Square) table for the responses and variables.

S.O.V	df	Bulb yield	N losses	NUE	WUE
Regression	9	193296480**	1697.6**	215928**	2.36**
Linear	3	270807185**	4637.8**	581539**	3.56**
Square	3	301563262**	307.5**	66186**	3.50**
Interaction	3	9518992*	147.5**	3322*	0.025ns
Residual error	10	2382007	3.1	163	0.020
Lack-of-fit	5	4655965^{ns}	6.2^{ns}	322^{ns}	0.039^{ns}
Pure error	5	2965049	4.7	119	0.013
Total	19	-	-	-	-
R^2 (%)	-	97.43	99.61	99.84	98.19

^{ns} = Non significant; * = Significant at 5% level; ** = Significant at 1% level.

That implies that a high proportion of the variability for these variables was explained by the fitted model (Table 5). There was a close correspondence between observed and estimated values of the all response variables based on 1:1 lines (Figure 1).

Bulb yield

The highest bulb yield (80459 kg ha^{-1}) was obtained by application of 250 kg N ha^{-1} and 9000 m^{3} water ha^{-1} with density of 50 plant m^{-2} while the lowest bulb yield was observed at the lowest levels of all combination treatments including 50 kg N ha^{-1}, 8000 m^{3} water ha^{-1} and 25 plant m^{-2} yielding 54275 kg ha^{-1} (Table 6). The effects of independent variables on fitted bulb yield curves by full quadratic polynomial equation are shown in Figure 2. The results of N rate and irrigation interactions revealed that the bulb yield was increased along with increasing of N fertilizer rate up to approximately 160 kg N ha^{-1} and thereafter decreased through higher N rate under lower irrigation levels (Figure 2). In contrast, the bulb yield remained unchanged after application of 160 kg N ha^{-1} at higher levels of irrigation. Analyses yielded the expected results since applied N fertilizer can provide a better plant growth and development (Ozer, 2003). Bybordi et al. (2005) reported that applications of 240 and 180 kg N ha^{-1} did not lead to significantly different onion yield. Increasing of irrigation water caused to increase in bulb yield and onion yield was fixed at high levels of irrigation (Figure 2). Therefore, the effect of N fertilizer on yield improvement could be increased at medium and high levels of irrigation which clearly suggest the importance of N and water management in onion production. Aminpour and Mousavi (2006) also reported that the onion yield was improved by increasing of irrigation water volume.

Bulb yield continued to increase up to closely 160 kg N ha^{-1} and then declined when averaged over density treatments (Figure 2). At medium levels of nitrogen use, onion plants produced higher bulb yield at the medium plant density compared with low and high densities

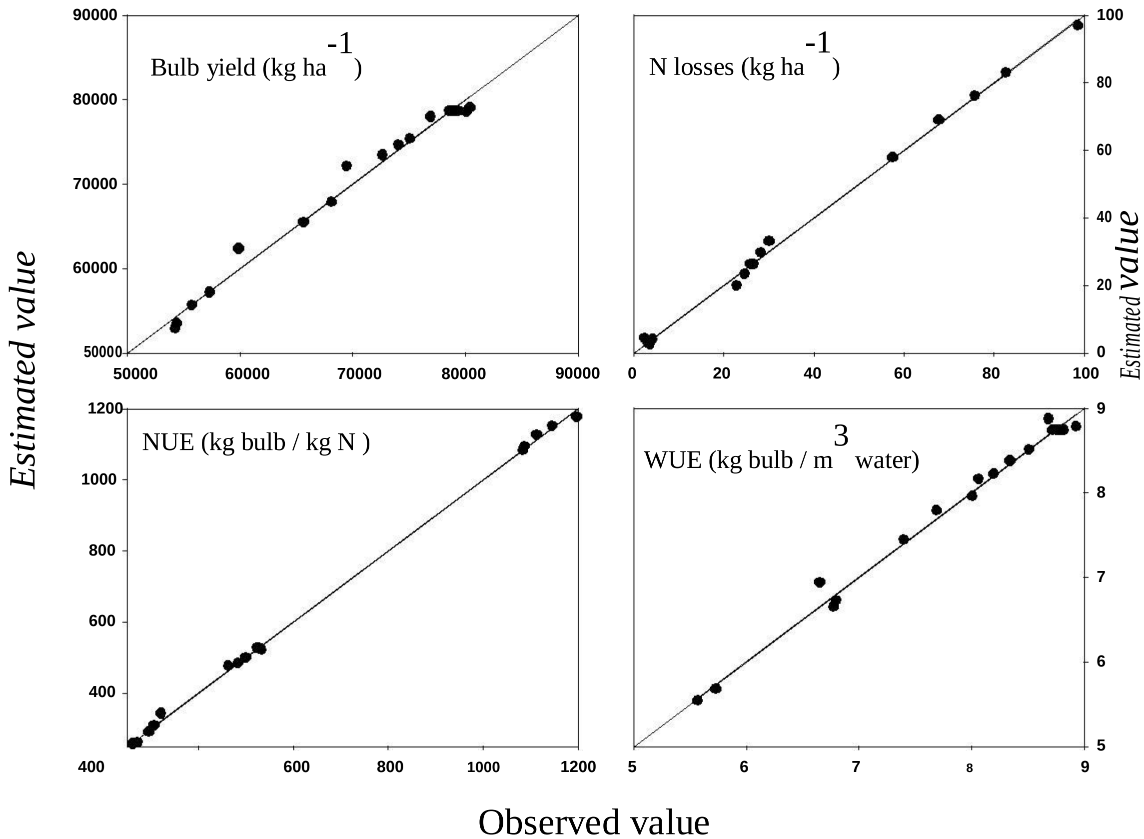

Figure 1. Comparison of estimated and observed value of bulb yield, N losses, NUE and WUE by 1:1 line.

Table 6. The response results for the study of three experimental variables in coded units.

Run	Factors			Responses			
	N fertilizer	Irrigation	Density	Bulb yield (kg ha^{-1})	N losses (kg N ha^{-1})	NUE (kg bulb/kg N)	WUE (kg bulb/m^3 water)
1	-1	-1	-1	54275	3.2	1088.00	6.80
2	+1	-1	-1	65683	67.8	272.40	8.51
3	-1	+1	-1	55746	4.2	1146.00	5.73
4	+1	+1	-1	74073	98.7	307.60	7.69
5	-1	-1	+1	54412	2.4	1084.00	6.78
6	+1	-1	+1	68145	57.6	262.40	8.20
7	-1	+1	+1	57332	3.6	1114.00	5.57
8	+1	+1	+1	76949	82.7	296.00	7.40
9	-1	0	0	59900	3.3	1198.00	6.66
10	+1	0	0	80459	75.8	321.60	8.93
11	0	-1	0	69500	22.9	463.33	8.69
12	0	+1	0	80129	30.1	534.00	8.01
13	0	0	-1	72675	28.3	500.67	8.34
14	0	0	+1	75109	24.7	484.00	8.07
15	0	0	0	79449	26.4	529.33	8.82
16	0	0	0	78580	25.9	523.33	8.72
17	0	0	0	78966	26.7	526.00	8.77
18	0	0	0	79191	26	527.33	8.79
19	0	0	0	79333	26.3	528.67	8.81
20	0	0	0	78819	26.2	525.33	8.76

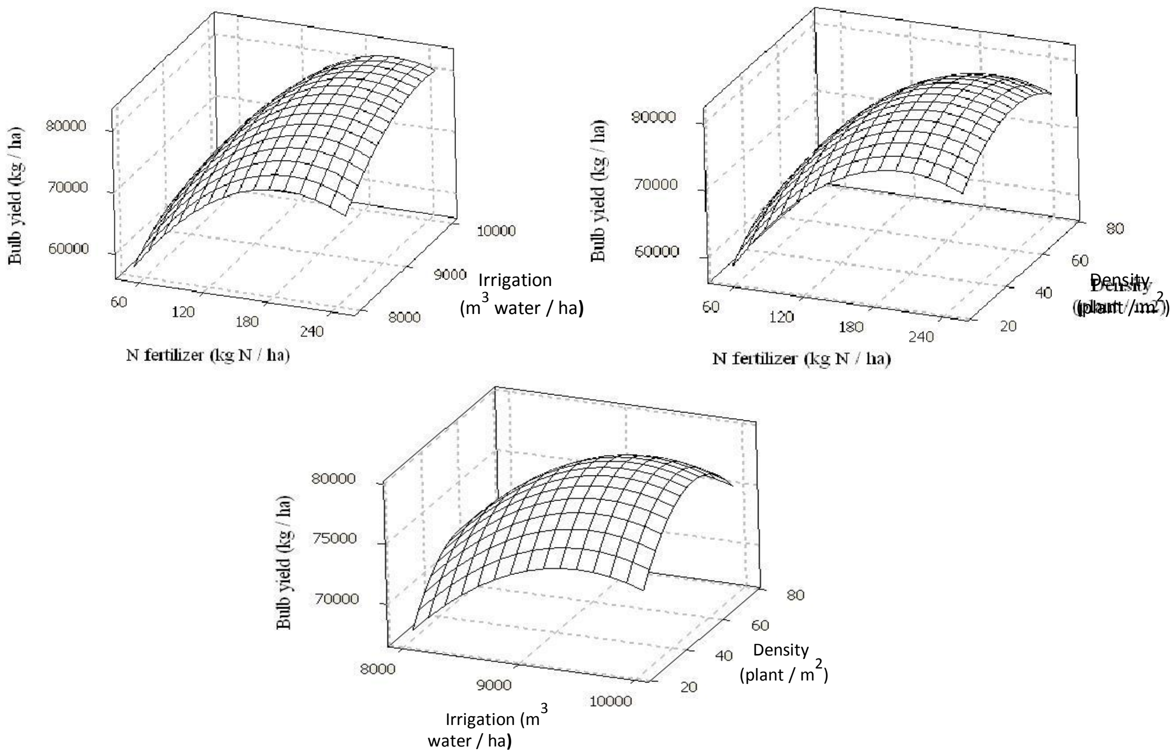

Figure 2. The bulb yield response to independent variables of N fertilizer, irrigation and density.

(Figure 2). The higher plant population may have reduced the onion bulb size due to the close plant spacing, consequently, resulted in decrease of bulb yield. It was found that the onion bulb yield was more influenced by N rate than plant density. That is to say, onion yield seemed to respond better to N rate changes compared to population density fluctuations. Findings of this study were similar to results of Afsar Manesh and Khodadadi (2006). They reported that the highest onion yield was obtained at a medium population of 66.7 onions m^{-2} with application of 180 kg N ha^{-1} indicating the effect of N rate × plant density interaction. The results illustrated that onion yield was improved until about 160 kg N ha^{-1}, however, the rate of 180 kg N ha^{-1} was reported as an optimum N amount in Jiroft region by Afsar Manesh and Khodadadi (2006). They found that N rate recommendations are site-specific and affected by environmental conditions, cultivar, residual soil N, N rate, and amount of mineralized N from soil organic matter sources. Therefore, to optimize N fertilizer recommendations for the individual crop, all effective parameters should be counted.

The trend changes of yield as affected by irrigation × density interactions were similar with the obtained trend for N rate × density interactions (Figure 2). Medium levels of irrigation and plant density produced greater bulb yield in comparison with low and high levels of irrigation. So that, Bulb yields were near to maximum with the application of 9000 m^3 water ha^{-1} and cultivation of 60 onions m^{-2} (Figure 2).

N losses

The N losses were ranged from 2.4 to 98.7 kg N ha^{-1} averaged over N rate, irrigation and density (Table 6). Application of 250 kg N ha^{-1}, 10000 m^3 water ha^{-1} with density of 25 plants m^{-2} resulted in the greatest N losses. Contrarily, the lowest amount was obtained by application of 50 kg N ha^{-1} and 8000 m^3 water ha^{-1} in 75 onions m^{-2} (Table 6). Decreasing N fertilizer, irrigation and increasing onion density may have caused the decline in N losses.

N fertilizer applications significantly affected N losses (Figure 3). N losses increased with increasing N rates when averaged over irrigation rates (Figure 3). Therefore, higher N rates had greater amount of N losses because higher application of N fertilizer may have led to more available N for leaching. This can result in higher N losses. The higher rate of N fertilizer led to low recovery of N due to losses through denitrification, ammonia volatilization, run off, leaching, and inefficient utilization by crops was reported as important constraints to N fertilizer use among farmers in the sub-region (Akintoye et al., 1999). Based on the effects of N rate × irrigation interactions on N losses, it can be concluded that an

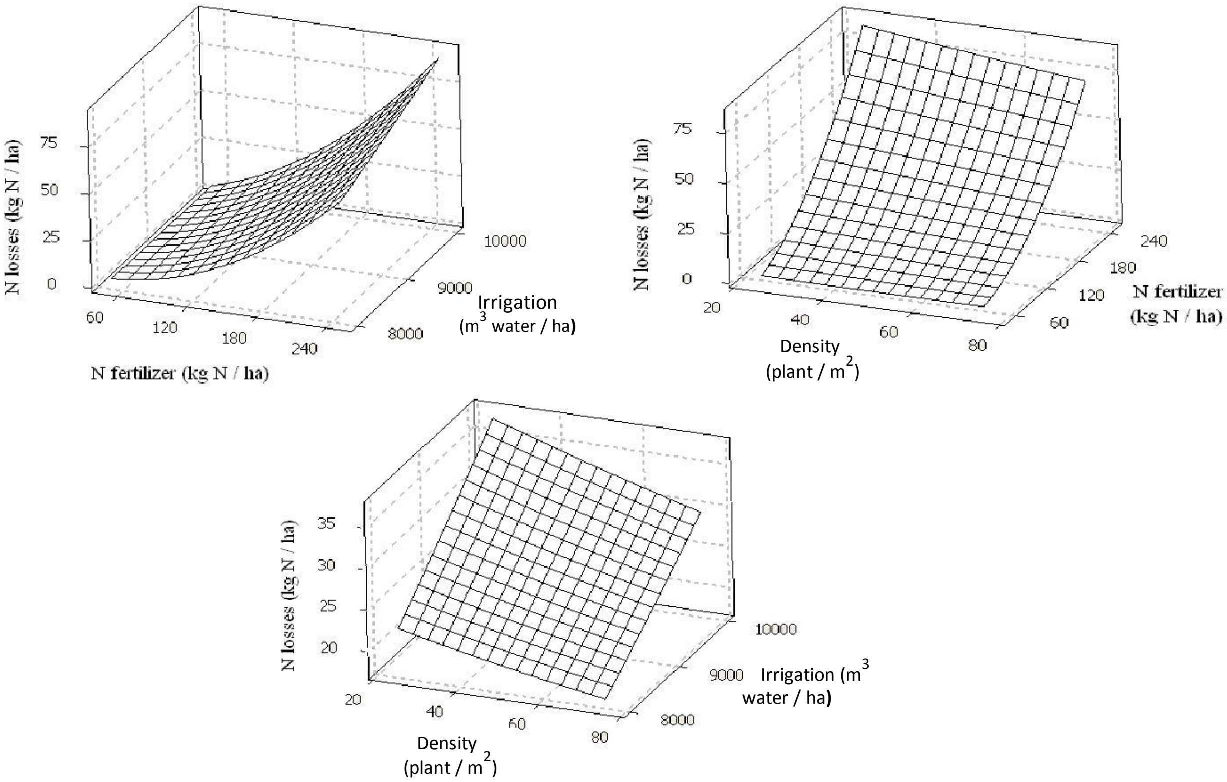

Figure 3. The N losses response to independent variables of N fertilizer, irrigation and density.

increase in irrigation amount at low levels of N rates led to no influence in N losses whereas, more N losses was found at high levels of N rates in the same conditions (Figure 3). Halvorson et al. (2008) reported that soil nitrate generally increased with increasing N rate leading to the increase of nitrate leaching potential. They also described that drip system reduced soil nitrate leaching compared with furrow system.

In terms of N losses, the N rate × density interaction did not differ between different rates of density under low application of N rates, and greater N losses with low density of onion in higher rates of N. Low application of N fertilizer in all onion density resulted in minimum losses of N (Figure 3). N losses were greater at the low density compared with high density averaged over N rates. High density of onion may be led to higher absorption of N and subsequently reduction of N losses due to increasing of contact surface of roots with soil in comparison with low density. N losses decreased with increasing onion density especially at higher levels of N fertilizer (Figure 3).

The highest N losses as affected by density × irrigation interactions were observed in low density and high level of irrigation. The lowest ones were obtained at the low irrigation under high density (Figure 3). The negative effect of irrigation on N losses was observed when irrigation volume increased causing higher losses of N at all levels of onion density. Decreasing of onion density was seen to increase N losses under all levels of irrigation (Figure 3). Application of more irrigation was associated with further available water for N leaching that caused to increase the N losses. In addition, higher N losses were found under more irrigated onion in low density compared with high density (Figure 3).

Nitrogen use efficiency (NUE)

Values of NUE ranged from 264.4 to 1198 kg bulb kg^{-1} N when averaged over N rate, irrigation and density (Table 6). Applying the highest rate of N (250 kg N ha^{-1}) and plant density (75 plants m^{-2}) at the lowest level of irrigation (8000 m^{3} water ha^{-1}) provided the lowest NUE (Table 6). The highest value of NUE was obtained by application of the lowest N rate (50 kg N ha^{-1}) at medium levels of irrigation (9000 m^{3} water ha^{-1}) and plant density of 50 plants m^{-2}, (Table 6). It seems that the medium plant density of onion improves NUE by increasing biomass which is led to reduce the N losses due to high absorption of N by developed roots.

NUE was significantly decreased with increasing N rate when is expressed as a function of bulb yield and N fertilizer averaged over irrigation and density. Simultaneous effects of N rate and irrigation on NUE

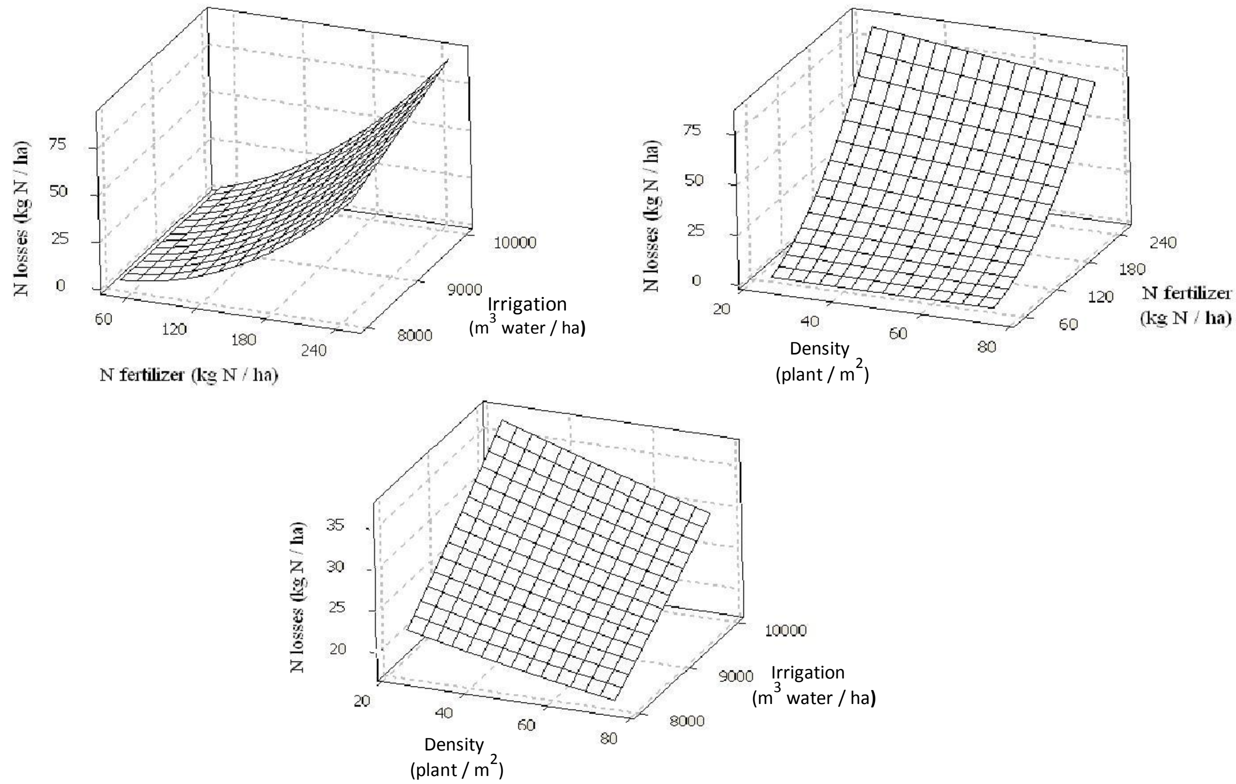

Figure 4. The NUE (kg bulb/ kg N) response to independent variables of N fertilizer, irrigation and density.

showed that NUE value was slightly enhanced by increase in irrigation volume at all levels of N rates; however, declined with increasing of N rate over irrigation amounts (Figure 4). Improvement of NUE was associated with lower N utilization and higher onion yield. Studying N fertilizer effects on onion by illustrated that increasing N fertilizer led to reduce the NUE (Halvorson et al., 2008).

NUE was reduced along with increasing N fertilizer at all plant densities (Figure 4). The results of N rate × density interaction showed no difference in NUE by changing the onion density and more influence of N rate on NUE. This reflects the greater response of NUE to N application than density (Figure 4). Maximum values of NUE were acquired by application of lower N fertilizer and the minimum values were observed at higher levels of N rates at over levels of plant densities (Figure 4). Because further increases in yield diminishes along with further increases in the amount of applied N fertilizer , that is, the efficiency of N utilization decreases as yield increases (Akintoye et al., 1999). It is well known that NUE decreases with increment of N availability (Chamoro et al., 2002; Svecnjak and Rengel, 2006).

Evaluating the effects of density × irrigation interaction on NUE illustrated that NUE was improved accompanied by increasing of irrigation up to medium levels and then reduced at all plant densities. Medium levels of onion density showed greater NUE than other densities when averaged over irrigation rates (Figure 4). Maximum and minimum values of NUE affected by irrigation × density interaction were gained at medium and low levels of irrigation and plant density, respectively (Figure 4).

Water use efficiency (WUE)

The highest WUE was obtained at 250 kg N ha^{-1}, 9000 m^3 water ha^{-1} and 50 plants m^{-2} whereas, the lowest amount of N (50 kg N ha^{-1}), 10000 m^3 water ha^{-1} and onion density (75 plants m^{-2}) showed the lowest WUE (Table 6). Since, the WUE is gained by ratio of yield and water consumption (Mandal et al., 2006), it seems that increasing of N level and cultivated onion at optimum level leading to improvement in WUE as well as enhancing of onion yield.

Assessing of response surface of WUE to irrigation × N rate interactions illustrated that the WUE was ameliorated as affected by increasing of N levels and deceasing of water levels (Figure 5). An increase in N rate led to WUE improvement under all irrigation levels. WUE increased with increasing N rate up to higher levels of N and then remained unchanged when averaged over irrigation rates (Figure 5). In all N levels, WUE was reduced as irrigation rates increased. Hence, the highest WUE was obtained in the highest level of N and the lowest irrigation level (Figure 5).

An increase in both independent variables including N

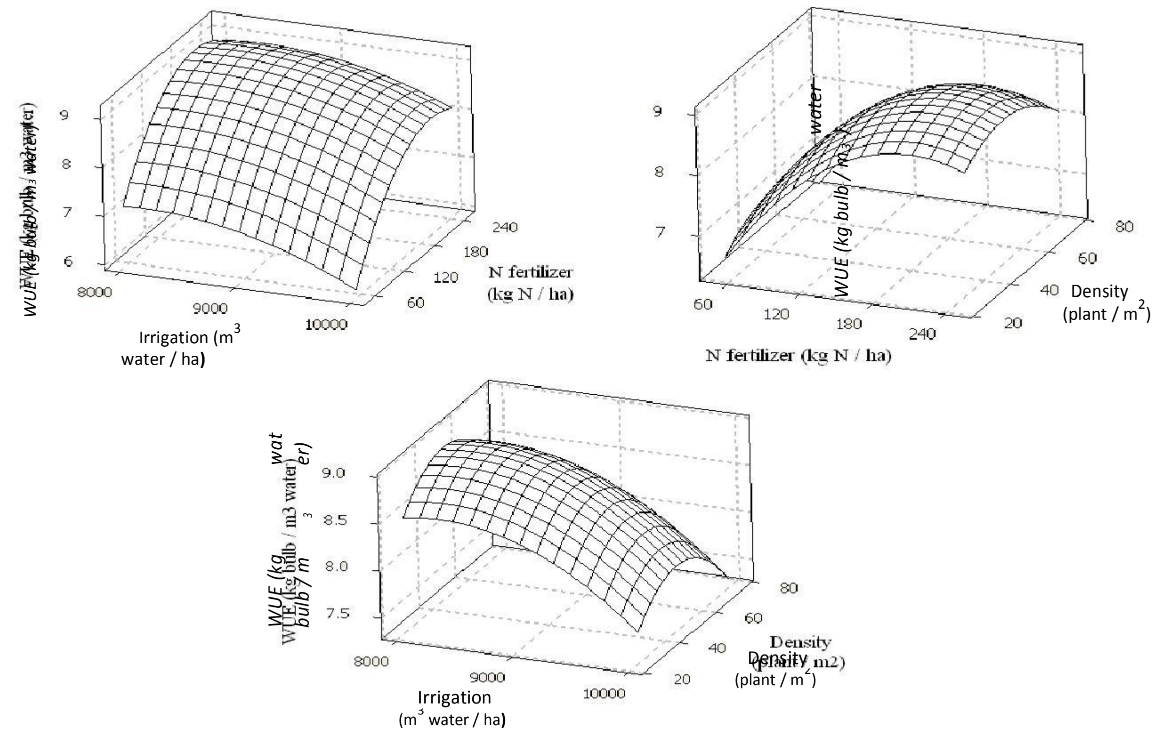

Figure 5. The WUE (kg bulb/ m^3 water) response to independent variables of N fertilizer, irrigation and density.

rate up to about 180 kg N ha^{-1} and plant density up to medium levels (nearly 50 plants m^{-1}) led to improvement of WUE (Figure 5). Therefore, optimum levels of density showed greater WUE compared with low and high plant densities at all rates of N. Applying N rate up to closely 180 kg N ha^{-1} resulted in increasing of WUE and then decreasing of WUE (Figure 5). More response of WUE to N fertilization in comparison with density was gained as a result of interaction between N rate × density interactions.

Surface response of WUE to irrigation × onion density interaction illustrated that WUE was remarkably declined with increase in irrigation amounts averaged over densities (Figure 5). On the other hand, the greater WUE was occurred at medium onion population (Figure 5). Dogan et al. (2011) found that the highest irrigation water use efficiency was acquired in the lowest level of irrigation water and this trait was decreased by increasing of irrigation levels. They reported that the water use efficiency obtained in the different treatments indicating a strong positive relationship between crop yield and irrigation volume.

Resource optimization

Optimum levels of N fertilizer, irrigation and onion density for achieving the targeted rates of responses based on three scenarios of economic, environmental and eco-environmental is shown in Table 7. Here, the composite desirability (0.90, 0.91 and 0.86 for economic, environmental and eco-environmental scenarios, respectively) is close to 1, which indicates the settings are appeared to achieve favorable results for all responses in all three scenarios. Onion bulb yield was considered as main variable to determine the optimum levels of recourses in economic scenario; accordingly the importance value for bulb yield was 2. This demonstrates the bulb yield was more important (as 2 times) than other responses. Values enclosed in the parenthesis are indicating the importance value for the response variables in each scenario. The results of economic scenario showed that application of 141 kg N ha^{-1} and 10000 m^3 water ha^{-1} at density of 53.1 plants m^{-2} resulted in 77547 kg bulb ha^{-1}, 32.10 kg N ha^{-1} as losses, 539.2 kg bulb kg^{-1} N for NUE and 7.55 kg bulb m^{-3} water for WUE (Table 7). With respect to applied N fertilizer (141 kg N ha^{-1}) to achieve the highest yield in economic scenario, it could be concluded that application of N fertilizer higher than 140 kg ha^{-1} had no significant effect on yield enhancement. Subsequently, surplus N was lost by leaching and emission which resulted in environmental pollutions. The determining variable to make a decision for optimizing of resource was N losses reduction under environmental scenario; therefore, importance value of N losses was 2 for this scenario. In environmental scenario, the main target was decreasing of environmental pollution with little attention to economic yield. The values of independent variables that suggested for environmental

Table 7. Optimizing of independent variables and obtained values for response variables.

Variable		Scenario		
		Economic	**Environmental**	**Eco-environmental**
Response variable	Bulb yield (kg ha^{-1})	77547 (2)	58861 (1)	70633 (1)
	N losses (kg N ha^{-1})	32.10 (1)	10.00 (2)	15.40 (1)
	NUE (kg bulb kg^{-1} N)	539.2 (1)	703.5 (1)	775.6 (2)
	WUE (kg bulb m^{-3} water)	7.55 (1)	7.10 (1)	7.98 (2)
Independent	N fertilizer (kg N ha^{-1})	141.2	82.50	93.48
	Irrigation (m^3 water ha^{-1})	10000	8528	8930
	Density (Plant m^{-2})	53.10	70.10	42.67
Composite desirability		0.90	0.91	0.86

scenario were 82.5 kg N ha^{-1}, 8528 m^3 water ha^{-1} and 70.1 plants m^{-2}. Based on proposed values for independent variables, the response variables (bulb yield, N losses, NUE and WUE) were estimated about 58861 kg bulb ha^{-1}, 10 kg N ha^{-1}, 703.5 kg bulb per one kg N and 7.1 kg bulb per one m^3 water, respectively (Table 7). To obtain the optimum levels of N, water and plant density in eco-environmental scenario, NUE and WUE were the main variables, so eco-environmental scenario was strongly affected by NUE and WUE and these variables was taken 2 as importance value. The proposed optimum rates of N fertilizer, irrigation and density would be 93.48 kg N ha^{-1}, 8930 m^3 water ha^{-1} and 42.67 onions m^{-2} in eco-environmental scenario based on fitted model (Table 7). The mentioned values of resources led to gain 70633 kg bulb ha^{-1}, 15.4 kg N ha^{-1}, 775.6 kg bulb kg^{-1} N and 7.98 kg bulb m^{-3} water for bulb yield, N losses, NUE and WUE, respectively (Table 7). The amount of N losses in environmental scenario was 68.85 and 35.06% smaller than economic and eco-environmental scenarios, respectively.

In essence, the eco-environmental scenario considers both bulb yield (as an economic index) and N losses (as an environmental index). So, using resource (water and N fertilizer) and plant density based on this scenario can be suggested as appropriate approach for achieving desirable yield with associated reduction of environmental pollution.

Conclusion

As results, to maximize onion bulb yield, N and water rates must be kept at the higher tested levels and the onion density at medium level. On the other hand, for minimizing N losses, the rate of N fertilizer and irrigation must be applied at the lowest tested levels while the density must be kept at the highest level. Although, the highest level of investigated treatments resulted in the highest onion yield, N losses were highly under this condition. Therefore, using resource use efficiency such as NUE and WUE as a criterion could ensure desirable yield, quality; then, utilize the resources effectively having a remarkable effect on environmental health. For economic scenario, the optimum value of N fertilizer, water and plant density were 141 kg N ha^{-1}, 10000 m^3 water ha^{-1} and 53 plants m^{-2}, respectively. The optimum amount of the variables was obtained by 82.5 kg N ha^{-1}, 8528 m^3 water ha^{-1} and 70 plants m^{-2}, respectively under environmental scenario. In the trial area, the farmers commonly apply more N fertilizer in onion farms which is associated with high N losses. Therefore, the results indicate that the application of 93.48 kg N ha^{-1} based on eco-environmental scenario can be optimized the resources use, reduced environmental hazards and produced acceptable onion yield.

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