Original Research Article

Optimizing garlic (*Allium sativum*) yield through irrigation scheduling and nitrogen management

ABSTRACT

Aims: Efficient utilization of natural resources, such as water and nutrients, plays a pivotal role in enhancing crop yield and overall productivity.

Study design:

Place and Duration of Study: To delve into the intricate interaction between water and nitrogen use efficiency in garlic cultivation, a two-year-long experiment was conducted.

Methodology: The experiment consisted of twelve treatment combinations, encompassing four distinct irrigation schedules (I0 as the control, I1 with 4 cm irrigation at an IW/CPE ratio of 0.8, I2 at 1.0, and I3 at 1.2) and three nitrogen levels (N0 as the control, N1 at 75%, and N2 at 100% of the recommended nitrogen dose).

Results: These treatments were replicated thrice using a factorial randomized block design. Notably, the irrigation schedule I3 exhibited a significant increase in nitrogen use efficiency, consequently resulting in higher garlic yields compared to the control irrigation (I0). Given the substantial difference in bulb yield observed in the I3 level (136.0 q/ha) compared to the control, it can be considered an efficient irrigation schedule for garlic cultivation. Among the tested nitrogen levels, N2 emerged as the most favorable, yielding significantly higher garlic production. The treatment combination of I3N2 recorded the highest bulb yield, boasting a remarkable increase of 64.5% over the control.

Conclusion: In summary, this study underscores the effectiveness of the I3N2 treatment combination for achieving robust growth and increased garlic yields while optimizing the utilization of irrigation water and nitrogen resources.

Keywords: Garlic, water use efficiency, nitrogen use efficiency, irrigation, yield

1. INTRODUCTION

The most important bulb crop garlic (*Allium sativum*) belongs to the family Alliaceae contains proteins, lipids, carbohydrates, fibre, alkaloids and vitamins uses as a food preservative. Garlicproductioninthecountryhasshownsteadyincreaseinlastfew yearsand it is the second most important bulb crop in India. The global scenario of area and production of garlic shows that it is grown in an area of 12 million hectares with a production of 16.4 million tons globally (FAO,2008).Although, the productivity of garlic in Himachal Pradesh is almost three times higher than that of national average, but it is still lower than its potential yield. There is a lot of scope to enhance its productivity by lowering down the gap between potential yield and actual yield (Zala *et al.* 2014). In many garlic producing areas, lack of available nutrients and availability of soil waterare two main limiting factors for the low productivity of garlic. Therefore, through proper irrigation and nutrient management practices we can enhance its productivityand bring it near to its potential yield.

The frequency of irrigation and the amount of water required are governed by various factors such as cultivar, soil types, season, distribution of rainfall and management practices etc (Singh *et al.* 2008). Irrigation scheduling is a water management strategy which prevent over application of water while minimizing the yield loss due to water shortage or drought stress. Both over irrigation as well as under irrigation adversely affect the garlic yield. The importance of irrigation scheduling is that it enables the irrigator to apply exact amount of water to achieve the goal of increased irrigation efficiency (Imitiyaz*et al*., 2000). On the other hand, judicious application of fertilizers is important for garlic production. Nitrogen fertilization is necessaryfor ensuring successful vegetative growth. However, it is most often the limiting nutrient element in plant growth and is a constituent of chlorophyll, plant proteins and nucleic acids. The efficient use of N from the economic point of view can be achieved by soil moisture management through efficient irrigation schedule. Keeping in view, a study carried out to develop an efficient irrigation schedule and nitrogen and irrigation interaction effect to achieve higher productivity along with water use efficiency in garlic.

2. MATERIAL AND METHODS

To achieve objectives of present study field experiments were conducted for two consecutive winter seasons 2017-2018 in the experimental farm, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

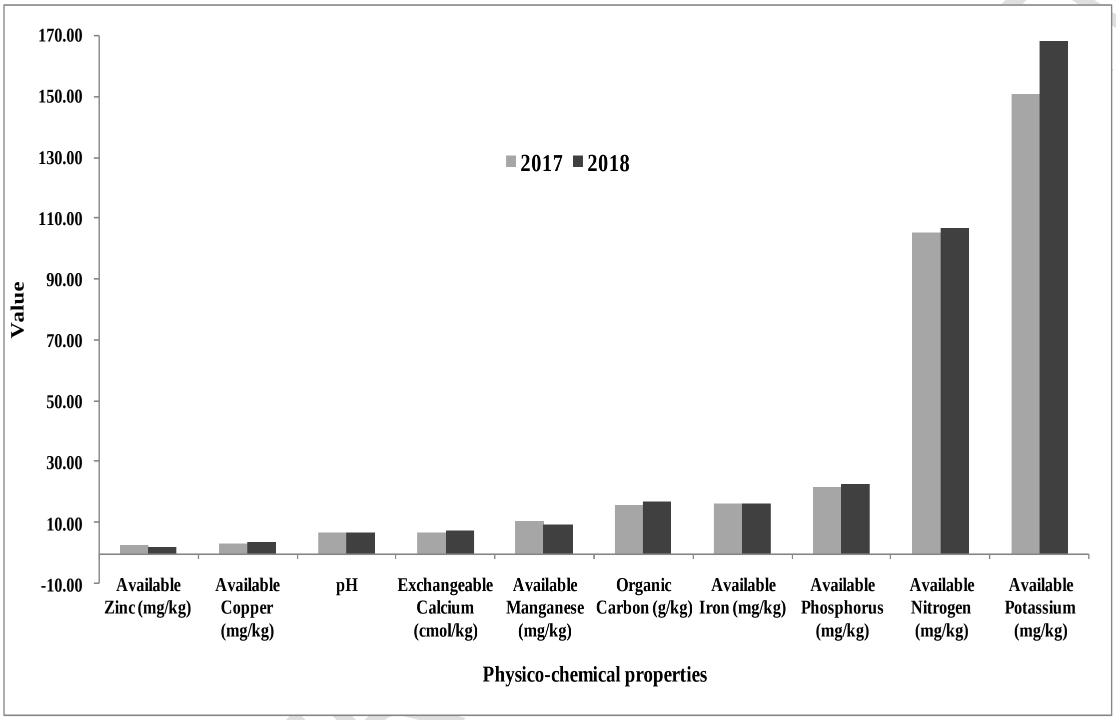

Figure 1. Physico-chemicalpropertiesoftheexperimentalsoil (depth 0-15 cm)

2.1 Soil analysis

Prior to conducting the experiment, representative soil samples were collected from a depth of 0-15 cm. These samples were gathered to investigate the impact of varying irrigation and nitrogen levels on several soil parameters, including pH, soil organic carbon, available nitrogen, phosphorus, potassium, exchangeable calcium, and the availability of micronutrient cations such as iron, manganese, zinc, and copper (Figure 1).

2.2 Experimentaldetails

A total of 12 treatment combinations, comprising different irrigation schedules (I0: 0.0 IW/CPE, I1: 0.8 IW/CPE, I2: 1.0 IW/CPE, I3: 1.2 IW/CPE) and nitrogen levels (N0: 0.0% N fertilizer, N1: 75% of N fertilizer, N2: 100% of N fertilizer), were arranged in a Factorial Randomized Block Design with three replications. The experimental field underwent thorough plowing using a tractor, followed by planking, 15 days prior to the actual sowing date. A total of thirty-six raised plots, each measuring 3 m × 2 m, were established. All the agronomic practices necessary for garlic bulb production were carried out according to recommended guidelines. To assess yield and related traits, including plant height (cm), number of leaves per plant, number of cloves per bulb, biological yield (q/ha), and bulb yield (q/ha), five plants were randomly chosen and marked in each treatment. The data recorded was analyzed by using MS-

Excel and OPSTAT software. Themean values of data were subjected to analysis of variance (ANOVA) as described by Panse and Sukhatme (2000) for using Factorial Randomized Block Design.

3. RESULTS AND DISCUSSION

Prior to conducting the experiment, the soil profile underwent meticulous analysis over two consecutive seasons at a depth of 0-15 cm. The findings indicated that all the examined physio-chemical properties exhibited statistically similar results (Figure 1).

Table 1. Effect of irrigation and N levels on plant height (cm), number of leaves per plant and number of cloves per bulb in garlic

Treatments		**Plant height (cm)**		**Number of leaves per plant**			**Number of cloves per bulb**		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
I0N0	39.20	47.20	43.20	7.50	8.50	8.00	10.30	10.50	10.40
I1N0	48.20	56.80	52.50	9.70	10.60	10.20	10.90	10.60	10.80
I2N0	50.00	57.60	53.80	9.70	11.30	10.50	10.90	11.10	11.00
I3N0	50.30	59.90	55.10	9.90	11.40	10.70	11.50	11.90	11.70
I0N1	50.40	53.10	51.70	10.40	10.80	10.60	11.70	11.80	11.70
I1N1	59.00	60.30	59.70	12.70	13.20	12.90	14.30	14.30	14.30
I2N1	61.50	63.70	62.60	12.70	13.30	13.00	14.30	14.50	14.40
I3N1	62.90	65.40	64.20	12.90	13.60	13.20	14.70	15.10	14.90
I0N2	52.70	59.30	56.00	11.00	11.60	11.30	11.90	11.90	11.90
I1N2	61.30	68.50	64.90	13.10	13.80	13.50	14.30	14.60	14.40
I2N2	65.60	70.10	67.90	13.20	13.90	13.60	15.40	15.10	15.20
I3N2	69.60	70.50	70.00	13.40	14.00	13.70	15.70	15.70	15.70
Mean	**55.89**	**61.03**	**58.47**	**11.35**	**12.17**	**11.77**	**12.99**	**13.09**	**13.03**
Critical Difference at 5% level of significance									
I	1.00	0.70	0.70	NS	0.20	NS	0.50	0.30	0.30
N	0.90	0.60	0.60	NS	0.20	NS	0.40	0.30	0.30
IxN	1.80	1.20	1.20	NS	NS	NS	0.80	0.60	0.50

I0: (Control), I1: (0.8 IW/CPE ratio), I2: (1 IW/CPE ratio), I3: (1.2 IW/CPE ratio)
N0: Control, N1: 75% of RDN, N2: 100% of RDN

3.1 Effects of irrigation scheduling and nitrogen levels on garlic production

3.1.1 Plantheight

An acquisition of the data in Table 1 showed statistically significant effect of irrigation levels, N levels and their interaction on plant height across years. However, in I3, plant height (60.9 and 65.3 cm) was significantly higher as compared to control (I0), while, N2 level exhibited significantly higher plant height (62.3 and 67.1 cm) across the years, respectively. Furthermore, interaction of I3 and N2 showed significantly highest plant height(69.6 cm and 70.5cm) in the respective years. Moreover, pooled analysis of data also showed the comparable results of main and interaction of water and nitrogen for plant height. The results of present study are also in close conformity with the findings of Aregawi (2006) and Farooqui *et al*. (2009) in garlic, who also reported that increased amount of N fertilizer applied, increased the plant height significantly. Kakar *et al*. (2002) and Gebrehaweria (2007) have also reported significant effect of N on plant height in garlic. The increase in height could also be attributed to the involvement of N in building blocks for the synthesis of amino acids, as they link together to form proteins and make up metabolic processes required for plant growth.

3.1.2 Numberofleavesperplant

The number of leaves per plant showed insignificant main (irrigation and nitrogen levels) and interaction effects in 2016-17 and pooled data (Table 1). In year 2017-18, main (irrigation and nitrogen levels) had significant effect but interaction had insignificant effect. Main effect I3 and N2 levels had significantly high number of leaves per plant (13.0 and 13.3) as compared to control, respectively. The results obtained are in line with those of Ahmed *et al*. (2007) and Ahmed *et al*. (2009) in garlic and Biswas *et al*. (2010) in onion who also observed that increasingtheirrigationfrequencycausedanincreaseinnumberofleavesperplant. The more number of leaves in plant grown under higher N level might have been associated with the application ofNin adequatequantitythatpositivelyimproved thevegetative growthofgarlic.

3.1.3 Numberofclovesperbulb

The number of cloves per bulb showed significant main effect (irrigationandNlevels) and interaction effect across years and pooled data (Table 1). In irrigation level, the highest number of cloves perbulb (13.9, 14.2 and 14.1) was observed in I3 level during 2016-17, 2017-18 and pooled data, respectively. Furthermore, in nitrogen level, N2 level exhibited the highest number of cloves perbulb (14.3 each) in 2016-17, 2017-18 and pooled data, respectively. The interaction (I×N) effect was also significant on number of cloves pre bulb in both the years and pooled data. These findings are in close agreement with other workers like Singh *et al*. (2007) and Doro (2012) in garlic. The results of Setty *et al*. (1989) also stated that applicationofNfertilizerssignificantlyincreasedbulbsizeandnumberofclovesingarlic.

3.1.4 Biologicalyield(q/ha)

In two consecutive years and pooled data of present study, the effect of irrigation and N levels and interaction effect on biological yield (q/ha) was found to be significant (Table 2). In irrigation level, I3 had significantly high mean biological yield (245.7and 269.4 q ha^{-1}) whereas in N levels, the N2 level had significantly high mean biological yield (261.5 and 282.2 q ha^{-1}) as compared to control (N_0 level) during both the years. In case of interaction effect (I×N) significantly higher biological yield of garlic (295.0 and 310.0 q ha^{-1}) was found in I_3N_2 in 2016-17 and 2017-18, respectively. Furthermore, in pooled data the I3 had significantly higher biological yield (257.5 q ha^{-1}) while N_2 level had significantly higher (271.9 q ha^{-1}) biological yield while In case of interaction effect I_3N_2 had significantly higher biological yield (302.5 q ha^{-1}). Higher biological yield of garlic under N_2 might be due to complete solubility, mobilization and availability of N at regular interval in required quantity. The reason suggested for such a response was that optimum N application increased growth parameters, which in turn synthesized more plant metabolites thereby, increasing crop yield Similar results were also reported by Narukа*et al*. (2005) and Gowda *et al*. (2007) in garlic.

Table 2. Effect of irrigation and N levels on bulb yield (q/ha) and biological yield (q/ha) in garlic

Treatments	**Bulb yield (Q/ha)**			**Biological yield (Q/ha)**		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
I0N0	87.30	100.00	93.80	155.20	175.30	165.20
I1N0	98.10	108.00	103.00	170.80	190.70	180.70
I2N0	102.40	117.00	110.00	177.90	202.00	190.00
I3N0	108.70	126.00	117.00	188.90	214.80	201.90
I0N1	101.70	119.90	110.80	171.50	197.10	184.30
I1N1	118.10	136.00	127.10	239.70	264.70	252.20
I2N1	121.10	142.30	131.70	245.30	273.60	259.50
I3N1	124.40	147.70	136.10	253.00	283.40	268.20
I0N2	111.70	129.30	120.50	196.10	222.00	209.10
I1N2	133.30	150.60	141.90	271.20	295.40	283.30
I2N2	142.90	153.80	148.30	283.80	301.50	292.60
I3N2	149.80	158.70	154.30	295.00	310.00	302.50
Mean	**116.63**	**132.44**	**124.54**	**220.70**	**244.21**	**232.46**
Critical Difference at 5% level of significance						
I	2.60	1.30	1.40	2.40	1.20	1.40

N	2.20	1.10	1.20	2.10	1.10	1.20
IxN	4.50	2.20	2.50	4.20	2.10	2.40

I0: (Control), I1: (0.8 IW/CPE ratio), I2: (1 IW/CPE ratio), I3: (1.2 IW/CPE ratio)
N0: Control, N1: 75% of RDN, N2: 100% of RDN

4.1.5 Bulbyield(q/ha)

Table 2 showed the significant main effect (irrigation and N levels) on bulb yieldduringboththe years and pooled data. In irrigation levels, during 2016-17, 2017-18 and pooled data I3 exhibited significantly highest bulb yield (127.6, 144.4 and 136.0 q/ha) whereas in nitrogen levels, N2 level had significantly highest bulb yield (134.4, 148.1 and 141.3 q/ha) as compared to control, respectively. Furthermore, interaction I3N2 was recorded significant during both the years and pooled data in this study. Higherbulbweightandbulbyieldwithirrigationlevel I_3mightbeduetooptimumsoilmoistureregimes(Table2)throughoutthegrowing period which might have facilitated greater nutrient uptake and proper soil physical environment to help the plant to put forth better vegetative growth and yield. BetterexpressionofgrowthandyieldunderhigherquantityofirrigationandNwas also reported by Singh *et al*. (2007) and Doro (2012) in garlic and Dorcas *et al*. (2012) and Kumar*etal*.(2007)inonion.TheenhancedbulbyieldunderN$_2$mightberelatedto sufficient application of N that significantly influenced the plant performance. Studies of Assefa *et al*. (2015) revealed that better N supply to the plant increased the rate of metabolism where more synthesis of carbohydrate takes place. This in turn increased the bulb weight and total yield of garlic. An adequatesupplyofN is therefore, associated with vigorous vegetative growth andmoreefficientuseofavailableinputsfinallyleadingtohigherproductivity. Improvementin overall growth i.e. plant height, leaf length and number of leaves with irrigation coupled with increased net photosynthesis towards reproduction structure, which increased the yield attributes significantly. These findings are in close agreement with previous studies i.e. Singh *et al*. (2007) and Doro (2012) in garlic and Dorcas *et al.* (2012) in onion.

Table3. Nitrogen and water useefficiency in garlic cultivation

Treatments	Nitrogen use efficiency (%)			Water use efficiency (%)		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
I0N0	-	-	-	373.7	294.3	334.0
I1N1	18.06	24.32	21.19	251.9	261.0	256.4
I2N2	31.71	32.58	32.15	247.0	262.5	254.8
I3N0	-	-	-	224.8	270.3	247.5
I0N1	14.51	18.64	16.58	435.0	351.9	393.5
I1N2	28.23	32.10	30.16	303.2	325.8	314.5
I2N0	-	-	-	292.1	317.6	304.9
I3N1	25.23	29.56	27.39	257.3	315.2	286.3
I0N2	19.92	24.31	22.11	477.8	379.3	428.6
I1N0	-	-	-	342.1	360.8	351.4
I2N1	20.29	25.34	22.82	344.7	343.4	344.0
I3N2	35.10	34.49	34.80	309.9	338.7	324.3

I_0: (Control), I_1: (0.8 IW/CPE ratio), I_2: (1 IW/CPE ratio), I_3: (1.2 IW/CPE ratio)
N_0: Control, N_1: 75% of RDN, N_2: 100% of RDN

3.2 Water and nitrogen use efficiency of garlic production

3.2.1 Nitrogenuseefficiency(NUE)(%)

It is evident from Table 3 that during 2016-17, the highest NUE (35.10 %) was observed under I_3N_2 followed by I_2N_2(31.71 %) and lowest (14.51 %) under I_0N_1followed by I_1N_1(18.06 %) while during 2017-18, the highest NUE (34.49 %) was recorded under I_3N_2 followed by I_2N_2 (32.58 %) and lowest (18.64 %) under I_0N_1 followed by I_0N_2 (24.31 %). On pooled basis, the highest NUE (34.80 %) was recorded under I_3N_2 and lowest (16.58 %) under I_0N_1. The results are in accordance with the findings of Liao *et al.* (2009) in radish andYadan and Xin (2017) in tomato who also reported that NUE increased with increase in the amount of water applied. Similar finding was observed by Yadav *et al*. (2010) in onion.

3.2.2 Wateruseefficiency(WUE)

Water use efficiency was calculated on the basis of yield and irrigation water applied during both the years of study. To maximize WUE, it is necessary to conserve water and to promote maximum crop growth. A perusal of data in Table 3 revealed that among irrigation levels, the highest WUE (428.8 and 341.8 kg ha^{-1} cm^{-1}) was recorded under I_0 and the lowest (264.0 and 308.0 kg ha^{-1} cm^{-1}) under I_3 irrigation level during both the years. Among N levels, highest WUE (575.1 and 434.6 kg ha^{-1} cm^{-1}) was noticed under N_2 and lowest (205.1 and 241.9 kg ha^{-1} cm^{-1}) under N_0 during both the years of study.On pooled data, the highest WUE was recorded under I_0(385.3 kg ha^{-1} cm^{-1}), which was 34.72 per cent higher over I_3(286.0 kg ha^{-1} cm^{-1})irrigation level. As WUE is the ratio of yield to that of water applied, comparatively lower water applied gave higher WUE. This might be due to inverse relation between WUE and amount of irrigation water applied. WUE decreasedwithhigherirrigationregime.Thismight beduetofactthattheincreasein yieldwas not proportionate to the increase in consumptive use of water. These results corroborated with the findings of Zala *et al*. (2014) in garlic, Singh *et al*. (2008) and Thenmozhi and Duraisamy (2014) in onion.

4. CONCLUSION

The study aimed to investigate the impact of varying irrigation schedules and nitrogen levels on garlic yield, as well as water and nitrogen use efficiency. Among tested nitrogen levels, N2 (at 100% of the recommended N dose) proved to be the most effective, resulting in notably higher garlic yields. Furthermore, irrigation schedule I3 demonstrated an increase in nitrogen use efficiency (NUE) and garlic yield when compared to the control irrigation schedule. When combined, irrigation schedule I3 with N2 substantially enhanced NUE in garlic compared to the control. The significant difference in garlic bulb yield observed under the I3N2 treatment combination makes it a compelling choice for achieving both higher garlic yields and improved water and nitrogen use efficiency. Based on the two-year study, it can be concluded that an efficient irrigation schedule and an appropriate nitrogen level are essential factors for maintaining optimal soil moisture conditions and creating a conducive environment for maximizing garlic growth and yield.

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