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Full Length Research Paper

Effect of plant density and nitrogen fertilizer on growth, yield and fruit quality of sweet pepper (*Capsicum annum* L.)

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The present research was carried out to evaluate response of sweet pepper (*Capsicum annum* L.) to plant density and nitrogen fertilizer under field conditions. Plant density at four levels (20×50 cm, 30×50 cm, 20×100 cm and 30×100 cm) and nitrogen treatments at four levels (0, 50, 100 and 150 kg N/ha) were applied. Plant height, lateral stem number, leaf chlorophyll content, yield, and vitamin C were assessed at immature and mature stages. The results showed that vegetative growth characteristics (plant height, lateral stem number and leaf dry matter) and reproductive factors (fruit volume, fruit weight and plant yield) decreased with increasing plant density, but total yield (kg/ha) increased with increasing plant density. The highest and lowest total yields were obtained by plant density 20×50 cm and 30×100 cm respectively. Nitrogen fertilizer was significantly affected on plant height, lateral stem number and leaf chlorophyll content. It was observed that fertilization with 50 kg N/ha resulted to the highest fruit volume and plant yield. There were significant differences between fruit volume and fruit weight by interaction between plant density and nitrogen treatments.

Key words: Plant density, nitrogen, pepper, yield, fruit quality.

INTRODUCTION

Vegetables are important sources of carbohydrates, proteins, vitamins, and minerals. Sweet pepper (*Capsicum annum* L.) which belongs to Solananceae, is known as a vegetable, and consumed both as fresh and dehydrated spices (Bosland and Vostava, 2000). Pepper is a good source of vitamins A, C, E, B_1, and B_2, potassium, phosphorus and calcium. Moreover, it is one of the valuable medicinal plants in pharmaceutical industries because of high amounts of antioxidant, capsaicin and capsantin as main active substances. Studies on plant density for different types of pepper including bell, cayenne, pepperoncini and Jalapeno have shown that plant density and plant arrangement can influence plant development, growth and the marketable yield of peppers (Khasmakhi-Sabet et al., 2009). Plant density is an important determinant of yield.

Yield per unit area tends to increase as plant density increases up to a point and then declines (Akintoye et al., 2009). Nasto et al. (2009) reported that increasing plant density resulted in greater yield (kg/ha) of bell pepper. Wider spacing on the other hand led to increase in fruit yield per plant with bigger fruits and more cracked fruits per plant in tomato (Law and Egharevba, 2009). It was observed that plant density significantly affected root weight of pepper (Viloria et al., 2002). The increase in yield with higher plant density was as a result of increased numbers of fruit per ha in direct-seeded paprika pepper (Cavero et al., 2001). The other management practices are fertilizer application, especially nitrogen in terms of kind and rate. It had been observed that Nitrogen fertilizer is an essential component of any system in which the aim is to maintain good yield (Law and Egharevba, 2009).

The productivity of pepper is highly responsive to N fertilizer. Tumbare et al. (2004) reported that nitrogen fertilizer increased fruit weight, yield and fruit number of chili peppers. Madeira and de Varennes (2005) observed

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Table 1. Soil characteristics of experimental field.

Parameter	Value
N (%)	0.05
P (cmol/kg)	0.093
K(cmol/kg)	1.42
pH	7.1
Clay (%)	19
Silt (%)	41
Sand (%)	40

Table 2. Treatments.

Plant density (cm)	Nitrogen fertilizer rate (kgha^{-1})			
	0 (control)	50 kg (N/ha)	100 kg (N/ha)	150 kg (N/ha)
20×50	A1	A2	A3	A4
30×50 cm	B1	B2	B3	B4
20×100 cm	C1	C2	C3	C4
30×100 cm	D1	D2	D3	D4

that total chlorophyll content, leaf N concentration and shoot dry weight of pepper increased with increasing N fertilization. Guohua et al. (2001) found that varying nitrogen form affected on sweet pepper flowering, fruit set, fruit ripening time and yield. Qawasmi et al. (1999) reported that increasing the rates of nitrogen applied in pepper plants increases the uptake of nitrogen by the plants and at the same time, stimulated the uptake of potassium and phosphorus through the synergistic effect of nitrogen on them. Thus, the main aims of this experiment were to find the best plant density and nitrogen level for sweet pepper cultivation under field status.

MATERIALS AND METHODS

Plant preparation

The investigation was conducted during the 2008 growing season at the experimental field of the Agricultural Faculty, University of Birjand (latitude 32°53′ N, longitude 59°13′ E and 1470 m elevation), Iran. This site represents the range of dry conditions. Annual rainfall ranges is between 91 and 120 mm and mean annual relative humidity is 37%. Soil sample (0 to 30 cm depth) was taken with auger after the site had been prepared for cultivation. The sample was analyzed for physical and chemical properties using standard laboratory procedures described by Mylavarapu and Kennelly (2002) and data shown in Table 1.

The experimental field was cleared, ploughed, harrowed and divided into plots. Phosphorus (P_2O_5) and potassium (K_2O_5) were applied 50 and 100 kg/ha each at the time of soil preparation. Sweet pepper seeds were established in a greenhouse in large trays with a 1:1 mixture of sand and peat (1:1 v/v). Irrigation was done after sowing when necessary. Six-week-old pepper plants were hand-transplanted into well-prepared beds in the field. Other horticultural operations including mulching, weeding and harvest were done every week.

Treatments

Treatments consisted of four planting densities (20×50, 30×50, 20×100 and 30×100 cm) and four levels of nitrogen (0, 50, 100, and 150 kg ha^{-1}) (Table 2). The source for nitrogenous fertilizer was urea (46%) that was split into three equal parts and applied at ten days after transplanting (DAP) as basal and remaining portions were used as top dressing at 30 and 50 DAP.

Measurements

Ten plants in each replication were used to assess plant height, number of lateral stem at three growing stages including vegetative, flowering and reproductive. Leaf chlorophyll content was measured by a portable chlorophyll meter, SPAD-502 (Minolta Corporation, Ramsey, NJ). Leave samples were oven dried at 70°C for 48 h to the constant leaf dry weight for each plant, which was weighed using a digital balance (Basela and Mahadeen, 2008). Mature fruits were harvested at 10 to 14 days intervals to assess the volume of fruits (cm^3), average fruit weight (g) and fruit yield per plant (g/plant). Fruit yield per hectare was obtained through conversion of the net plot yield. Vitamin C was determined based upon the quantitative discoloration of 2,6-dichlorophenol 2 indophenols (Merck KgaA, Darmstadt, Germany) titrimetric method as described in AOAC methodology No. 967.21 (AOAC 2000).

Experimental design and statistical analysis

A 4×4 factorial experiment arranged in a completely randomized block design (RCBD) with three replications and each replication

Table 3. Effect of plant density and nitrogen fertilizer application on vegetative characteristics of pepper.

Treatments	Plant height (cm)		Lateral stem number
	Veg.	Flower	Veg.
20×50 cm with N(0)	8.33^{d}	18.670^{fg}	5.660^{f}
20×50 cm with N(50)	10.0^{bc}	20.33^{efg}	8.00^{cd}
20×50 cm with N(100)	10.0^{bc}	19.67^{efg}	9.00^{abc}
20×50 cm with N (150)	8.330^{d}	20.67^{def}	8.66^{bcd}
30×50 cm with N(0)	9.0^{cd}	18.330^{g}	6.330^{f}
30×50 cm with N(50)	10.67^{b}	20.67^{def}	8.33^{cd}
30×50 cm with N(100)	11.00^{b}	20.33^{efg}	7.66^{de}
30×50 cm with N(150)	10.0^{bc}	21.00^{cde}	8.33^{cd}
20×100 cm with N(0)	10.33^{bc}	20.33^{efg}	6.66^{ef}
20×100 cm with N(50)	12.67^{a}	22.67^{bcd}	8.66^{bcd}
20×100 cm with N(100)	13.00^{a}	22.67^{bcd}	9.66^{ab}
20×100 cm with N(150)	11.33^{a}	24.330^{ab}	8.33^{cd}
30×100 cm with N(0)	11.00^{b}	21.33^{cde}	6.66^{ef}
30×100 cm with N(50)	13.00^{a}	23.00^{abc}	9.00^{abc}
30×100 cm with N(100)	13.67^{a}	24.670^{ab}	10.00^{a}
30×100 cm with N(150)	13.67^{a}	25.000^{a}	8.66^{bcd}

Veg.: Vegetative stage; Flower: flowering stage. Within each column, same letter indicates no significant difference between treatments at 5% levels.

Table 4. Effect of plant density and nitrogen fertilizer application on vegetative characteristics of pepper.

Treatments	Leaf chlorophyll		Leaf dry matter	
	Veg.	Flower	Veg.	Flower
20×50 cm with N(0)	58.67^{e}	56.00^{d}	12.00^{f}	20.33^{ef}
20×50 cm with N(50)	67.00^{abc}	69.33^{a}	13.67^{def}	22.33^{bcd}
20×50 cm with N(100)	67.33^{abc}	68.33^{ab}	14.67^{cde}	22.00^{cde}
20×50 cm with N (150)	63.33^{b-e}	67.67^{ab}	13.00^{ef}	22.00^{cde}
30×50 cm with N(0)	59.67^{de}	60.00^{cd}	12.00^{f}	19.67^{f}
30×50 cm with N(50)	67.33^{abc}	62.0^{bcd}	15.00^{bcd}	21.00^{def}
30×50 cm with N(100)	62.00^{cde}	67.33^{ab}	14.67^{cde}	22.33^{bcd}
30×50 cm with N(150)	70.00^{ab}	69.67^{a}	14.67^{cde}	22.00^{cde}
20×100 cm with N(0)	66.00^{a-d}	63.67^{abc}	12.67^{f}	21.00^{def}
20×100 cm with N(50)	66.33^{a-d}	68.00^{ab}	15.67^{abc}	25.00^{a}
20×100 cm with N(100)	69.67^{ab}	68.00^{ab}	16.67^{ab}	24.00^{ab}
20×100 cm with N(150)	64.33^{a-d}	67.00^{ab}	16.33^{abc}	23.33^{abc}
30×100 cm with N(0)	59.67^{de}	58.67^{cd}	12.33^{f}	22.00^{cde}
30×100 cm with N(50)	70.670^{a}	70.00^{a}	15.67^{abc}	25.00^{a}
30×100 cm with N(100)	66.00^{a-d}	64.67^{abc}	17.33^{a}	24.00^{ab}
30×100 cm with N(150)	64.67^{a-d}	65.00^{abc}	16.33^{abc}	24.00^{ab}

Veg.: Vegetative stage; Flower: flowering stage. Within each column, same letter indicates no significant difference between treatments at 5% levels.

had 10 plants. Data were analyzed using MSTAT-C and means were compared by Duncan’s multiple range test (DMRT) at 5% level of confidence.

RESULTS AND DISCUSSION

Data (Tables 2 to 5) showed that plant density and

Table 5. Effect of plant density and nitrogen fertilizer application on yield and fruit quality of pepper.

Treatments	Fruit F.W. (g)	Fruit vol. (cm^3)	Vit-C (mg/100 g)		Plant yield (g/plant)	Total yield (kg/ha)
			Green fruit	Red fruit		
20×50 cm with N(0)	50.43^{d}	118.3^{gh}	121.7^{de}	193.7^{def}	1259^{ef}	125960^{d}
20×50 cm with N(50)	58.07^{bcd}	135^{def}	123.3^{cd}	194.3^{def}	1352^{def}	135200^{b}
20×50 cm with N(100)	69.16^{a}	151.7^{bc}	124.3^{c}	195.3^{de}	1640^{b-f}	164060^{a}
20×50 cm with N (150)	56.66^{bcd}	131.7^{efg}	123.3^{cd}	196.0^{cd}	1292^{ef}	129260^{c}
30×50 cm with N(0)	54.54^{cd}	115.0^{h}	120.7^{e}	191.3^{f}	1077^{f}	71810^{j}
30×50 cm with N(50)	58.08^{bcd}	140.0^{cde}	123.3^{cd}	195.0^{de}	1462^{c-f}	97450^{f}
30×50 cm with N(100)	57.84^{bcd}	138.3^{cde}	124.3^{c}	194.7^{de}	1191^{ef}	97400^{f}
30×50 cm with N(150)	57.10^{bcd}	133.3^{efg}	123.3^{cd}	195.7^{cd}	1410^{def}	94030^{g}
20×100 cm with N(0)	66.30^{ab}	121.7^{fgh}	121.7^{de}	192.3^{ef}	1293^{ef}	64660^{k}
20×100 cm with N(50)	66.34^{ab}	160.00^{b}	126.3^{ab}	200.3^{a}	1689^{b-e}	84450^{h}
20×100 cm with N(100)	71.17^{a}	176.70^{a}	126.3^{ab}	199.7^{ab}	2084^{ab}	104210^{e}
20×100 cm with N(150)	63.70^{abc}	153.3^{bc}	124.7^{bc}	196.7^{bcd}	1870^{a-d}	93510^{g}
30×100 cm with N(0)	68.82^{a}	133.3^{efg}	122.0^{de}	196.7^{bcd}	1609^{b-f}	53630^{l}
30×100 cm with N(50)	69.85^{a}	180.0^{a}	127.3^{a}	199.7^{ab}	2300^{a}	76670^{i}
30×100 cm with N(100)	63.39^{abc}	178.3^{a}	127.7^{a}	201.0^{a}	1984^{abc}	66120^{k}
30×100 cm with N(150)	56.03^{cd}	150.0^{bcd}	124.7^{bc}	198.7^{abc}	1474^{c-f}	49130^{m}

F.W.: Fresh weight; Vol.: volume; W.: weight. Within each column, same letter indicates no significant difference between treatments at 5% levels.

nitrogen fertilization significantly affect pepper growth, yield and fruit quality.

Vegetative growth

Plant height and lateral stem number

Effect of nitrogen: Nitrogen fertilizer application lead to increased plant height at vegetative and flowering stages (Table 3). The levels of 100 and 150 kg N ha^{-1} nitrogen fertilizer produced the tallest plants and the shortest plants were formed in the control; however, no significant difference was found between three treatments: 50, 100 and 150 kg N ha^{-1}. The obtained results were in agreement with others (Bar et al., 2001; Bowen and Frey, 2002). Height of plant can be considered as one of the indices of plant vigor ordinarily and it depends upon vigor and growth habit of the plant. Soil nutrients are also very important for the height of plants.

Therefore, a higher dose of nitrogen increased plant height (Pervez et al., 2004). The effect of nitrogen fertilizer on the lateral stems number of pepper was significant (Table 3). The highest number of lateral stems (9.08) was obtained at 100 kg N ha^{-1} (at vegetative stage); however, at the flowering stage no significant differences were found between treatments. This was also in agreement with Bar et al. (2001).

Effect of plant density: Results obtained indicated significant differences for plant height (Table 3). The highest plant height (at vegetative and flowering stages) were observed in density 30×100 cm with 13.67 and 25.00 cm respectively and these variables decreased as plant density increased.

Similar results were also reported by others (Elattir, 2002; Viloria et al., 2002; Ara et al., 2007). The effect of plant density on the lateral stems number of pepper was significant. The plant density also had significant effect on lateral stems number (Table 3). The highest lateral stems number (8.58) was obtained at 30×100 cm; however, no significant differenceswas found between treatments at flowering stage. This result is the same trend with the findings of Jovicich and Cantliffe (2002) and Majnoun et al. (2006).

The reduction in plant height and lateral stems number as plant population density increased might be attributed to the possible competition for soil moisture and nutrients. Forbes and Watson (1994) explained that as plant population density increases, competition for available water, mineral nutrients and light increases (Samih, 2008).

Leaf chlorophyll content

Effect of nitrogen

The effect of nitrogen fertilizer level on leaf chlorophyll content was significant (Table 4). Results indicated the highest and lowest leaf chlorophyll content were observed at 50 kg N/ha and control plants (at vegetative and flowering stages) but there was no significance between nitrogen levels at the reproductive stage. Similar results have been reported in investigations conducted by Bowen and Frey (2002), Aroiee and Omidbaigi (2004) and Basela et al. (2008).

A promotion effect of inorganic fertilizers on chlorophyll contents might be attributed to the fact that nitrogen is a constituent of chlorophyll molecule. Moreover, nitrogen is the main constituent of all amino acids in proteins and lipids that act as structural compounds of the chloroplast (Basela and Mahadeen, 2008).

Effect of plant density

Plant density significantly did not affect on leaf chlorophyll contents.

Leaf dry matter content

Effect of nitrogen

The effect of nitrogen fertilizer level on leaf chlorophyll content was significant (Table 4), but the difference between 50, 100 and 150 kg N ha^{-1} treatments were not statistically significant at vegetative and flowering stages (Table 4). The highest leaf dry matter content was obtained at 50 and 100 kg N ha^{-1} application (at vegetative and flowering stages respectively) while the least leaf dry matter content was obtained in the control.

Similarly, Magdatena (2003) reported that leaf dry matter content increased as nitrogen rate increased. Takebe et al. (1995) reported that increments in leaf dry weight may be due to a combination of nitrogen with plant matter produced during photosynthesis such as glucose, ascorbic acid, amino acids and protein. Also, Tei et al. (2000) reported that increasing the rate of nitrogen fertilizer, significantly increased the dry weight of lettuce leaves.

Effect of plant density

It was observed that plant density had remarkable effect on leaf dry matter content (Table 4). The highest leaf dry matter content were obtained at density 20×100 cm with 16.67 and 25% (at vegetative and flowering stages, respectively) while the least leaf dry matter content were obtained at density 20×50 and 30×50 cm with 12.0% (at vegetative stage) and 30×50 cm with 19.67% (at flowering stage). This result confirms the earlier observations by Cavero et al. (2001) in paprika pepper, Viloria et al. (2002) in pepper and Ezz (2009) in pea. Higher plant density also restricts light penetration and dry matter accumulation, thus reducing flowering bud development (Foster et al., 1993). Moreover, the strong interplant competition due to crowding and the shallow taproot system of these plants may have prevented the absorption of water and nutrients at deeper soil profiles (Kebe et al., 1998).

Reproductive growth

Fruit weight and volume

Effect of nitrogen: Nitrogen fertilizer significantly affected the average fruit weight and fruit volume (Table 5). Data showed that the highest fruit weight and volume fruit were observed from 50 and 100 kg N ha^{-1} treatments (71.17 g, 180.0 cm^3), while the lowest belonged to the control (50.43 g, 115.0 cm^3). These results are consistent with those reported by Bar et al. (2001), Magdatena (2003), Akanbi et al. (2007) and Aujla et al. (2007) who also reported that increasing the rate of nitrogen fertilizers increases the average fruit weight and volume of pepper.

Effect of plant density: Table 5 shows that plant density significantly affected fruit weight and volume. Plant density 20×100 and 30×100 cm produced the highest weight and volume of fruit respectively (71.17 g, 180.0 cm^3), while the lowest fruit weight (50.43 g) and fruit volume (115.0 cm^3) was related to plant density 20×50 and 30×50 cm respectively. Gene (2002) and Jovicich and Cantliffe (2003) reported similar findings with increasing average fruit weight with wider spacing.

Interaction effect: The significant fertilizer × spacing interaction effect was observed on fruit average weight (Table 5). The highest fruit weight (71.17 g) was observed from a combination of 20×100 cm with 100 kg N ha^{-1}, while the lowest fruit weight (50.43 g) was observed from a combination of 20×50 cm with 0 kg N ha^{-1}. Changes in growth differences could be attributed to reduced competition for available nutrients in the soil and light energy. While higher planting densities adversely affect growth and yield of individual plants, total biomass produced per unit area increase with density. Thus within limits, high density planting compensate for the decreased weight of the individual plants.

Plant yield (g/plant)

Effect of nitrogen

Plant yield was affected by nitrogen fertilizer (Table 5). The highest yield in plant was obtained in 2300 (g/plant) after application of 50 kg ha^{-1}; the lowest yield was obtained in 1077 (g/plant) in the zero nitrogen application, that is the control that were in agreement with Tei et al. (2000), Tumbare et al. (2004) and Law and Egharevba (2009) reported that increments in the nitrogen rate of the fertilizers increased the yield and fruit number. Increasing

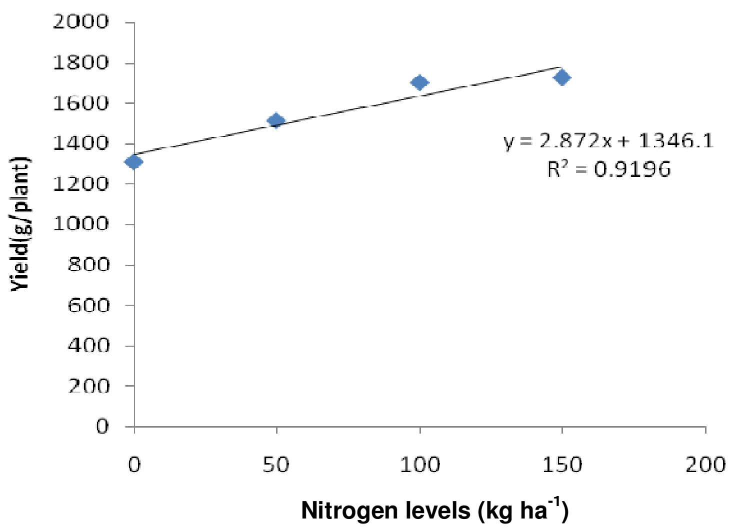

Figure 1. The correlation between nitrogen level and pepper plants yield.

the nitrogen levels of the fertilizers to 50 kg N ha^{-1} significantly increases the yield of pepper while yield decreases at the highest nitrogen dose. This reduction in yield might be due to toxicity in the plant (Boroujerdnia and Ansari, 2007). The marked effect of nitrogen on yield might be due to the cumulative stimulating effect of nitrogen on the vegetative growth characters which form the base for flowering and fruiting. The relationship between nitrogen level and pepper yield is shown in Figure 1. The equation was:

$$Y = 0.1603x + 81.062$$

where Y is yield in g/plant and X is nitrogen applied in ha.

Effect of plant density

Table 5 shows that plant density significantly affected fruit yield (g/plant). The highest and lowest plant yields were observed in the 30×100 cm with 1842 g and 30×50 cm with 1285 g respectively (Table 5). This result is in conformity with the findings of Cavero et al. (2001), Dean et al. (2006), Ara et al. (2007) and Nasto et al. (2009).This might be due to the effect of competition. This arose due to the fact that competition is less in low planting density than in high planting density. The competition might be high for nutrients, physical spaces and water (Law and Egharevba, 2009).

Total yield

Effect of nitrogen

Total yield was affected by nitrogen fertilizer (Table 5). Total yield decreases as nitrogen fertilizer increased up to 150 kg N/ ha^{-1}. The highest yield was obtained from 100 kg N/ha while minimum yield was recorded from 150 kg N/ha. The relationship between nitrogen level and pepper yield is shown in Figure 2. The equation was:

$$Y = 2.872x + 1346.1$$

where Y is yield in ton per ha and X is nitrogen applied in kg ha^{-1}.

Effect of plant density

The result of this experiment indicated that total yield was affected by plant density (Table 5). Yield per hectare increased as plant density increases. The highest density (20×50 cm) produced the highest fruit yield (kg ha^{-1}) while the lowest yield per hectare (49130 kg ha^{-1}) was recorded at density (30×100 cm). Similarly, Russo (2003), Nasto et al. (2009) and Khasmakhi-Sabet et al. (2009) reported that the greatest fruit yield (kg ha^{-1}) of sweet pepper and other plants were obtained from plants grown at high density.

Lower planting densities per unit area produces more vigorous crops than at higher population density, but this could not compensate for a reduced number of plants per unit area. The total yield increased with higher planting densities. This was probably due to increase in the number of plants per unit area, which might contribute to the production of extra yield per unit area leading to high yield (Law and Egharevba, 2009).

Vitamin C

Effect of nitrogen

Our result showed that nitrogen fertilization significantly

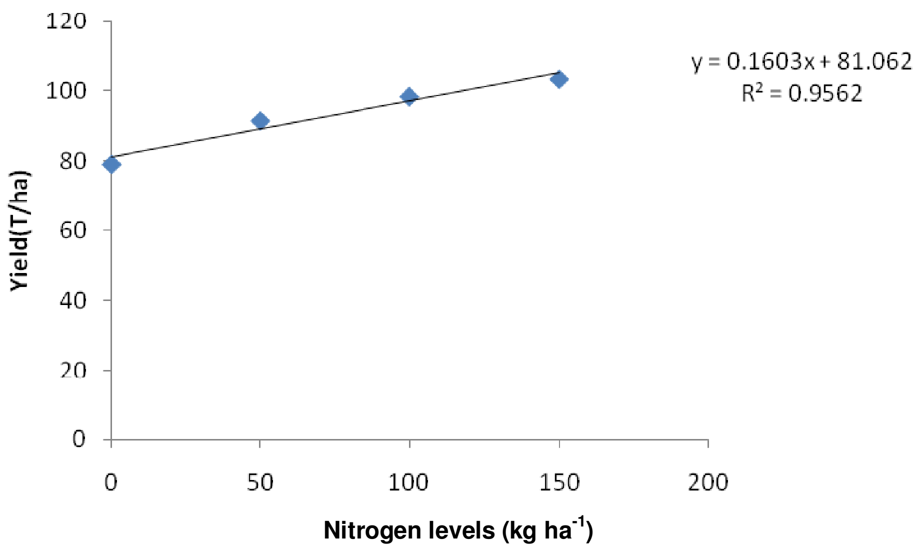

Figure 2. The correlation between nitrogen level and pepper yield per hectare.

increased vitamin C when compared to control (Table 5). As data shown, nitrogen fertilizer affected vitamin C content of fruit; increment of nitrogen levels from 50 to 150 kg N ha^{-1} reduced vitamin C content at green and red fruit stages (Table 5). Mozafar (1993) reported the positive and negative effects of nitrogen on vitamin C content of fruits, which was disagreement with Anita et al. (2009) who reported that increasing the rate of nitrogen fertilizers decrease vitamin C content of pumpkin.

Effect of plant density

A significant difference among the plant density treatments was found on vitamin C (Table 5). The highest vitamin C at green stage (127.7 mg/100 g) and ripping stage (201.0 mg/100 g) was observed in 30×100; while the lowest vitamin C at green stage (120.7 mg/100 g) and ripping stage (191.3 mg/100 g) was observed in 30×50 cm.

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