



Original article

Role of nitrogen and magnesium for growth, yield and nutritional quality of radish



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ABSTRACT

Nitrogen (N) affects all levels of plant function from metabolism to resource allocation, growth, and development and Magnesium (Mg) is a macronutrient that is necessary to both plant growth and health. Radish (*Raphanus sativus* L.) occupies an important position in the production and consumption of vegetables globally, but there are still many problems and challenges in its nutrient management. A pot trial was conducted to investigate the effects of nitrogen and magnesium fertilizers on radish during the year 2018–2019. Nitrogen and magnesium was applied at three rates (0, 0.200, and 0.300 g N kg⁻¹ soil) and (0, 0.050, and 0.100 g Mg kg⁻¹ soil) respectively. The experiment was laid out in a completely randomized design (CRD) and each treatment was replicated three times. Growth, yield and quality indicators of radish (plant height, root length, shoot length, plant weight, total soluble sugar, ascorbic acid, total soluble protein, crude fiber, etc.) were studied. The results indicated that different rates of nitrogen and magnesium fertilizer not only influence the growth dynamics and yields but also enhances radish quality. The results revealed that the growth, yield and nutrient contents of radish were increased at a range of 0.00 g N. kg⁻¹ soil to 0.300 g N. kg⁻¹ soil and 0.00 g Mg. kg⁻¹ soil to 0.050 g Mg. kg⁻¹ soil and then decreased gradually at a level of 0.100 g Mg. kg⁻¹ soil. In contrast, the crude fiber contents in radish decreased significantly with increasing nitrogen and magnesium level but increased significantly at Mg₂ level (0.050 g Mg. kg⁻¹ soil). The current study produced helpful results for increasing radish quality, decreasing production costs, and diminishing underground water contamination.

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1. Introduction

Vegetables are important agricultural products indispensable to people's lives, and the vegetable industry is an important industry related to the national economy and people's livelihood (Sahu, 2004). Radish (*Raphanus sativus* L.) is a root vegetable whose taproot is enlarged to form fleshy root as the edible organ widely cultivated around the globe, and is a nutritionally well-balanced vegetable in existence (Liao et al., 2009). Carbohydrate, protein, crude fiber and vitamin C are the nutritious constituents of radish (Bakhsh et al., 2006), broadly used as core plant, green sprouts and

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flabby leaves (Alam et al., 2010). Radish is the second largest type of vegetable in China (Zhang et al., 2019) and largely cultured all over the subcontinent of Indo-Pak (Bakhsh et al., 2006), covers a planting area of 10133 ha with total production of 173,806 tons in Pakistan (Jatoi et al., 2011). It has been observed that radish being cultivated by the vegetable growers in Pakistan is low in yield and quality (Pervez et al., 2004). Due to nitrate accumulating, underdeveloped root system and having short plant growing period, radish needs high amount of simply accessible nutrients in soil mainly nitrogen (Yuan et al., 2014).

Nitrogen (N) fertilization is essential for the production of vegetables to ensure sufficient yields and excellent quality (Zhang et al., 2015; Tilman et al., 2002). N considers one of the significant macronutrient among all the mineral elements for all living tissues of the plant from metabolism to resource allocation, growth and development (Stitt and Krapp, 1999; Crawford, 1995). Nitrogen application upholds the overall growth, yield and quality of radish (Khatri et al., 2019). However, N fertilizer with high application rates not only caused reduced crop yields but also adversely affected crop quality (Hu et al., 1992; Chen et al., 2004). This frequent and inadequate practices certainly cause environmental problems mainly nitrate (NO_3^-) loss in the environment (Ji et al., 2006). Some common practices are supposed to cause surface and ground water pollution such as heavy irrigation combined with high application rates of N fertilizer through soil erosion and nitrate (NO_3^-) leaching (Wang et al., 2002; Gastal and Lemaire, 2002). Leafy vegetables have ability to absorb excessive quantity of nitrogenous fertilizer for their better yield and quality. However, the excessive use of nitrate nitrogen in alkaline soils effectively enhances nitrate leaching. NO_3^- greatly involved probably in gastric cancer, occurrence of methaemoglobinemia and other diseases (Ishiwata et al., 2002; Ikemoto et al., 2002). So, accumulation of nitrates in plants is major concern and general problem in most crops (Cárdenas-Navarro et al., 1999). Effective use of N helps to reduce the cost of N-fertilizer inputs and to minimize nitrate contamination.

Magnesium (Mg) is recognized as an essential nutrient for various living organisms including, plant species, and animals and as well as human beings and thereby its deficiency may cause the reduction in productivity and quality in agriculture (Bennett 1993; Aitken et al., 1999; Hermans et al., 2004) and forestry (Mitchell et al., 1999). Magnesium is integral part of chlorophyll, photosynthesis, enzymes activator, building of nucleic acids, carbohydrate metabolism and stimulates phosphorus uptake and transport (Fageria and Gheyi, 1999; Nguyen et al., 2016; Lasa et al., 2000). Magnesium deficiency proved negative effects on mulberry plants in an experiment performed by Tewari et al. (2006). Thus, it's an important task to maintain the quantity of Mg in agricultural products within sufficient amount. Nitrogen and magnesium are considered important nutrients for growth, production and fruit quality (Nguyen et al., 2016) and therefore needed in adequate amounts, especially at critical crop growth stages, and development (Alva et al., 2006).

Dependence on the utilization of mineral fertilizer has brought about high agricultural production (Rathke et al., 2006). Managing agricultural nutrients to provide a safe food supply and environment security remains one of the immense challenges of the 21st-century (Yousaf et al., 2017). Radish occupies an important position in the production and consumption of vegetables globally, but there are still many problems and challenges in its nutrient management. Therefore, the nutrient management of vegetables is very important for the rational use of nutrients in our country and for coordination of economic, agronomic and environmental benefits. To best of our knowledge, no one has reported nitrogen and magnesium fertilization response on radish growth, yield and quality, especially in Pakistan. Therefore present study was

conducted to find out the effect of different levels of nitrogen and magnesium on growth, yield (plant height, root length, shoot length, plant weight, etc.) and nutrient contents (total soluble sugar, ascorbic acid, total soluble protein, crude fiber, etc.) of radish.

2. Materials and methods

2.1. Description of study site and experimental operation

A pot experiment was conducted during the year 2018–2019 at the research area of Ghazi University, Punjab, Pakistan (29°38'32" N, 70°35'45"E). The overall climate of the study area is dry with little rainfall, classified as BWh (Excess of evaporation over precipitation). The winter is mild, but it is very hot in summer. The average high temperature during summer is about 107 °F (42 °C), while during winter the average low is 40 °F (4 °C). Large size pots (30 cm with diameter, 50 cm with depth) were used that were closed at the bottom to avoid the N losses via leaching. Soil (0–20 cm depth) was collected from the field of experimental site and was tested to measure the physical–chemical characteristics of soil by following the method of Yousaf et al. (2016). Soil pH, Organic C, Total N, Olsen-P, and $\text{NH}_4\text{OAc-K}$ were observed 7.24, 0.56%, 0.023%, 8 ppm, 172 ppm, respectively and soil texture was classified as loamy soil. Each pot was filled with 14 kg of air dried soil (pass through a 0.5-mm sieve). Local promote seed of radish (Late sown Japani variety) was used as experimental cultivar for its extensive adaptability to climate and high yield and sowing was done at November 13.

The study was laid out in a completely randomized design (CRD) with nine treatments (Table 1) and each treatment was replicated three times. Nitrogen fertilizer (46.4% N) was applied as urea in two splits, 60% as a basal application and remaining 40% as topdressing at December 13. All pots were fertilized with the constant dose of phosphorus (P) and potassium (K) fertilizers. The P fertilizers (P_2O_5 5.2%) were applied 100% as a basal application (0.150 g P. kg^{-1} soil) as single superphosphate, while K fertilizers (K_2O 52.3%) were applied at the rate of 0.200 g K. kg^{-1} soil in two splits, 60% before sowing of radish and 40% as topdressing at December 13. Magnesium fertilizer was applied in the form of magnesium chloride ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$) in two splits, 60% as a basal dressing and remaining 40% as topdressing at December 13. A PVC tube was installed in each pot to allow aeration and water contents were maintained with deionized water. All experimental operations including, irrigation, herbicide application, and control of pest and disease were performed uniformly with local recommendation. No attacks of disease, weather, weeds or pest were recorded during the growth season of radish crop and harvesting was done at February 18.

Table 1
Different levels of nitrogen and magnesium application on growth, yield and quality of radish.

Treatment description	Nitrogen levels (g N. kg^{-1} soil)	Magnesium levels (g Mg. kg^{-1} soil)
N_1Mg_1	0.000	0.000
N_1Mg_2	0.000	0.050
N_1Mg_3	0.000	0.100
N_2Mg_1	0.200	0.000
N_2Mg_2	0.200	0.050
N_2Mg_3	0.200	0.100
N_3Mg_1	0.300	0.000
N_3Mg_2	0.300	0.050
N_3Mg_3	0.300	0.100

2.2. Sampling and measurement

Three radish seeds were sown and thinned to one plant per pot soon after emergence. To investigate the overall effect of nitrogen and magnesium fertilization on growth and nutrient contents of radish, all the fleshy root and leaf samples were collected at the mature stage. The plant samples were cleaned with deionized water and divided into roots and shoots section. Fresh and dry weight of roots and leaves were observed and expressed as g. pot⁻¹. Chlorophyll concentrations in leaves were recorded at maturity using the SPAD-502 meter (Konica-Minolta, Japan). Fresh radish roots and leaves were sampled for the analysis of nitrate reductase activity (NRA) and ascorbic acid (Vitamin C). NRA was determined by following the method of [Aslam et al. \(2001\)](#) while ascorbic acid was determined by the 2, 6-dichloro-indophenol titration method ([Lu, 2000](#)). The subsamples of root and leaf were dried in a forced-air oven at 65 °C for 24 h, ground in a mill, and then will placed in plastic bags until analysis for soluble sugar and crude fiber. Total soluble sugar (TSS) and crude fiber (CF) were determined by following the method of [Lowell et al. \(1989\)](#) and [Lu \(2000\)](#) respectively. Root and leaf samples from each treatment were dried at 60 °C to a constant weight. Ground samples were analyzed for the total nitrogen with a modified Kjeldahl method in which NO₃⁻ was reduced by salicylic acid ([Lu, 2000](#)) while magnesium contents were determined by atomic absorption spectrophotometer by the method of [Zhang et al. \(2014\)](#). Total soluble protein (TSP) was determined by spectrophotometer under the wavelength of 464 nm ([Lu et al., 2008](#)).

2.3. Data collection and analysis

The data were statistically analyzed by using the SPSS 17.0 (IBM) software program. The differences among the treatments were separated using least significance difference test (LSD) at 0.05 probability level. Figures were prepared using the Microsoft Office (MS EXCEL 2013) software.

3. Results

3.1. Effect of nitrogen and magnesium on radish growth

Different combination of N and Mg fertilizer application demonstrated significant influence among the growth attributes of radish. The growth dynamics of radish treated with different nitrogen and magnesium interactions are shown in [Table 2](#). Significantly maximum number of leaves (38.00), leaf length (28.67 g) and leaf weight (19.00 g) of radish were observed under N₃Mg₂ (0.300 g N. kg⁻¹ soil + 0.050 g Mg. kg⁻¹ soil) while minimum number of leaves (22.67), leaf length (11.83 g) and leaf weight (2.67 g) were recorded in N₁Mg₁ (control) level ([Table 2](#)). N₃Mg₂ combination of N and Mg fertilizer produced significantly highest root length (36.33 cm),

shoot length (27.67 cm) and plant height (64 cm) in radish as compared to N₁Mg₁ level of N and Mg application where lowest root length (27.33 cm), shoot length (11.00 cm) and plant height (38.33 cm) of radish were observed ([Table 2](#)). Similarly, a significant increase were observed in root diameter (23.67 cm), shoot diameter (29.33 cm) and chlorophyll concentration in leaves (40.93) when radish plant was treated with 0.300 g N. kg⁻¹ soil and 0.050 g Mg. kg⁻¹ soil (N₃Mg₂) as compared to control (N₁Mg₁) where root diameter (11.67 cm), shoot diameter (12.67 cm) and chlorophyll concentration in leaves (11.39) decreased significantly ([Table 2](#)). It can be seen from the results ([Table 2](#)) that with the increase of nitrogen fertilizer application, the growth dynamics of radish were increased at a range of 0.00 g N. kg⁻¹ soil to 0.300 g N. kg⁻¹ soil while the growth response of radish increased with the increase of magnesium fertilizer application at a range of 0.00 g Mg. kg⁻¹ soil to 0.050 g Mg. kg⁻¹ soil and then decreased gradually at a level of 0.100 g Mg. kg⁻¹ soil. Furthermore, the growth indicators of radish were affected by different combination of nitrogen and magnesium application rates as follows: N₃Mg₂ > N₃Mg₁ > N₃Mg₃ > N₂Mg₂ > N₂Mg₁ > N₂Mg₃ > N₁Mg₂ > N₁Mg₃ > N₁Mg₁.

3.2. Effect of nitrogen and magnesium on radish yield

The yields of radish were significantly influenced by the application of various nitrogen and magnesium treatments ([Table 3](#)). The highest root fresh weight (734 g) and root dry weight (640 g) were recorded when radish was fertilized at 0.300 g N. kg⁻¹ soil + 0.050 g Mg. kg⁻¹ soil while lowest root fresh weight (99 g) and root dry weight (102 g) of radish were noticed under N₁Mg₁ level ([Table 3](#)). Similarly, the maximum shoot fresh weight (314 g) and shoot dry weight (104 g) of radish were observed under N₃Mg₂ (0.300 g N. kg⁻¹ soil + 0.050 g Mg. kg⁻¹ soil) treatment while minimum shoot fresh weight (38 g) and shoot dry weight (15 g) were recorded in N₁Mg₁ (control). The results showed that the plant fresh weight (1048 g) and plant dry weight (745 g) yields of radish were significantly increased under N₃Mg₂ level as compared to control (N₁Mg₁) where plant fresh weight (138 g) and plant dry weight (118 g) yields of radish decreased significantly ([Table 3](#)). The analysis shows that the radish yields were significantly higher in pots receiving nitrogen as compared to the pots having no nitrogen and the increase of nitrogen application also increased the yields significantly while, the radish yields increased with the increase of magnesium fertilizer application at a range of 0.00 g Mg. kg⁻¹ soil to 0.050 g Mg. kg⁻¹ soil and then decreased gradually at a level of 0.100 g Mg. kg⁻¹ soil. Though, there is no statistically significant difference in the radish yields were observed among the different magnesium application levels but the average results showed an increasing trend, which became the biological basis for increasing the yield of radish. However, the fresh and dry weight yields of radish were affected by different

Table 2

Growth characteristics of radish affected by different combination of nitrogen and magnesium application.

Treatments	No of Leaves	Leaf Length (cm)	Leaf Weight (g)	Root Length (cm)	Shoot Length (cm)	Plant Height (cm)	Root Diameter (cm)	Shoot Diameter (cm)	Leaves Chlorophyll Conc. (SPAD Value)
N ₁ Mg ₁	22d	11.83d	2.67c	27.33b	11.00c	38.33d	11.67c	12.67d	11.39d
N ₁ Mg ₂	27d	13.00d	4.00c	30.00ab	12.67c	42.67cd	14.17c	13.83cd	16.32cd
N ₁ Mg ₃	23d	12.50d	3.33c	28.67ab	12.33c	41.00cd	12.50c	13.17d	12.03d
N ₂ Mg ₁	30bc	20.67c	12.00b	32.00ab	22.67ab	54.67ab	21.67a	21.00b	22.70bcd
N ₂ Mg ₂	34ab	23.67bc	12.67b	32.33ab	23.33ab	55.67ab	22.00a	21.33b	27.30abc
N ₂ Mg ₃	28cd	20.33c	9.33b	30.33ab	20.67b	51.00bc	18.00b	20.00bc	19.13cd
N ₃ Mg ₁	35ab	27.00ab	17.67a	36.00a	26.33a	62.33a	23.17a	26.33ab	35.50ab
N ₃ Mg ₂	38a	28.67a	19.00a	36.33a	27.67a	64.00a	23.67a	29.33a	40.93a
N ₃ Mg ₃	34ab	25.33ab	16.67a	33.00ab	26.00ab	59.00ab	22.50a	25.17ab	33.77ab

Mean values within a column for each treatment followed by different letters are significantly different at $P < 0.05$ according to LSD.

Table 3
The fresh and dry weight yields of radish affected by different combination of nitrogen and magnesium application.

Treatments	Root Fresh Weight (g)	Shoot Fresh Weight (g)	Plant Fresh Weight (g)	Root Dry Weight (g)	Shoot Dry Weight (g)	Plant Dry Weight (g)
N ₁ Mg ₁	99d	38c	138d	102d	15d	118e
N ₁ Mg ₂	154d	48c	202d	167d	18d	186e
N ₁ Mg ₃	127d	40c	167d	122d	17d	140e
N ₂ Mg ₁	524bc	182b	706bc	450bc	45c	495cd
N ₂ Mg ₂	551bc	195b	746bc	517ab	46c	563c
N ₂ Mg ₃	388c	181b	569c	327c	41c	369d
N ₃ Mg ₁	664ab	300a	964a	637a	74b	712ab
N ₃ Mg ₂	734a	314a	1048a	640a	104a	745a
N ₃ Mg ₃	591ab	283a	874ab	524ab	72b	596bc

Mean values within a column for each treatment followed by different letters are significantly different at P < 0.05 according to LSD.

combination of nitrogen and magnesium application rates as follows: N₃Mg₂ > N₃Mg₁ > N₃Mg₃ > N₂Mg₂ > N₂Mg₁ > N₂Mg₃ > N₁Mg₂ > N₁Mg₃ > N₁Mg₁.

3.3. Nitrogen, magnesium contents and nitrate reductase activity in roots and leaves of radish

The results of study revealed a significant effect of different nitrogen and magnesium fertilizer levels on the total nitrogen, magnesium contents and nitrate reductase activity (NRA) in roots and leaves of radish. The significantly highest N in roots (3.02%), N in leaves (2.45%) and total N (5.46%) in radish plant (roots + leaves) were noticed when N and Mg was applied at a rate of 0.300 g N. kg⁻¹ soil and 0.050 g Mg. kg⁻¹ soil respectively. N₃Mg₂ level of nitrogen and magnesium found statistically significant as compared to all other levels of N and Mg applied on radish while the lowest N in roots (1.62%), N in leaves (0.73%) and total N (2.35%) in radish plant (roots + leaves) were observed under N₁Mg₁ (control) (Fig. 1). Magnesium contents in roots (241–1210 ppm d.wt.), Mg in leaves (240–965 ppm d.wt.) and Mg contents (481–2175 ppm d.wt.) in plant (roots + leaves) were recorded in radish treated with different levels of N and Mg application. Higher Mg contents were absorbed in roots (6268 ppm d.wt.) as compared to leaves (5537 ppm d.wt.) of radish while significantly highest Mg contents (2175 ppm d.wt.) were observed in N₃Mg₂

level and lowest Mg contents (481 ppm d.wt.) were recorded in N₁Mg₁ treatment (Fig. 2). Furthermore, regarding nitrate reductase activity, highest NRA was found in leaves (259 μmol NO₂ g⁻¹ FW h⁻¹) as compared to roots (195 μmol NO₂ g⁻¹ FW h⁻¹) of radish while significantly maximum NRA (65.30 μmol NO₂ g⁻¹ FW h⁻¹) was observed in radish fertilized with N and Mg application at a rate of 0.300 g N. kg⁻¹ soil and 0.050 g Mg. kg⁻¹ soil respectively and minimum NRA (19.07 μmol NO₂ g⁻¹ FW h⁻¹) was noticed in N₁Mg₁ level having zero N and Mg application (Fig. 3). The results revealed that the total N, Mg contents and NRA in roots, leaves and plant (roots + leaves) of radish were higher in pots receiving N and Mg application as compared to the pots having no nitrogen and magnesium. Moreover the total nitrogen, magnesium contents and nitrate reductase activity were affected by different combination of nitrogen and magnesium application rates as follows: N₃Mg₂ > N₃Mg₁ > N₃Mg₃ > N₂Mg₂ > N₂Mg₁ > N₂Mg₃ > N₁Mg₂ > N₁Mg₃ > N₁Mg₁.

3.4. Effect of nitrogen and magnesium on radish quality

Data pertaining to the quality indicators including total soluble protein (TSP), total soluble sugar (TSS), ascorbic acid (Vitamin C) and crude fiber (CF) in roots and leaves of radish varied significantly among different N and Mg fertilization treatments. The highest TSP (27.21 mg/g f.wt.) and TSS (3.18 mg/g f.wt.) were

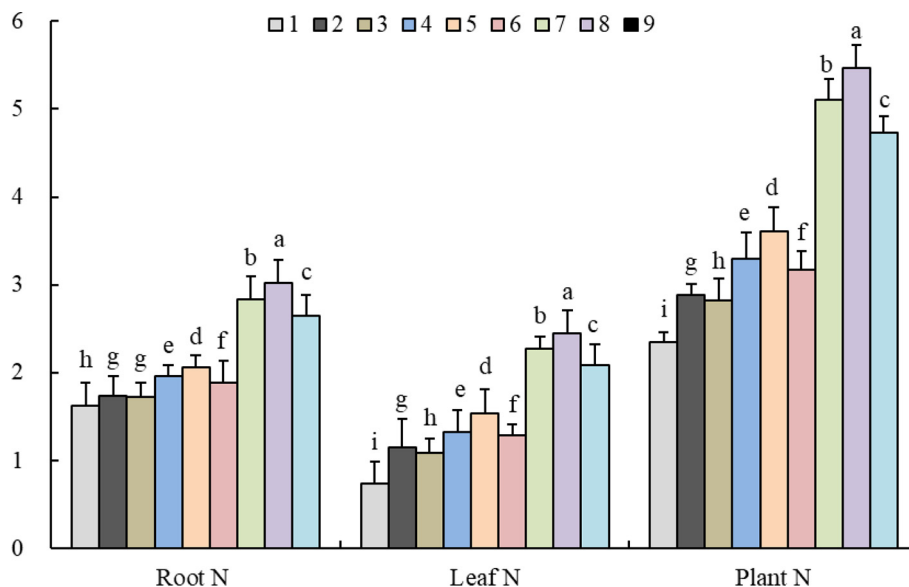


Fig. 1. Effect of nitrogen and magnesium application on total nitrogen in roots, leaves and plant of radish. Each value represent the standard deviation (n = 3) and expressed in %. Mean values followed by different letters are significantly different at P < 0.05 according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N₁Mg₁, N₁Mg₂, N₁Mg₃, N₂Mg₁, N₂Mg₂, N₂Mg₃, N₃Mg₁, N₃Mg₂, and N₃Mg₃ respectively.

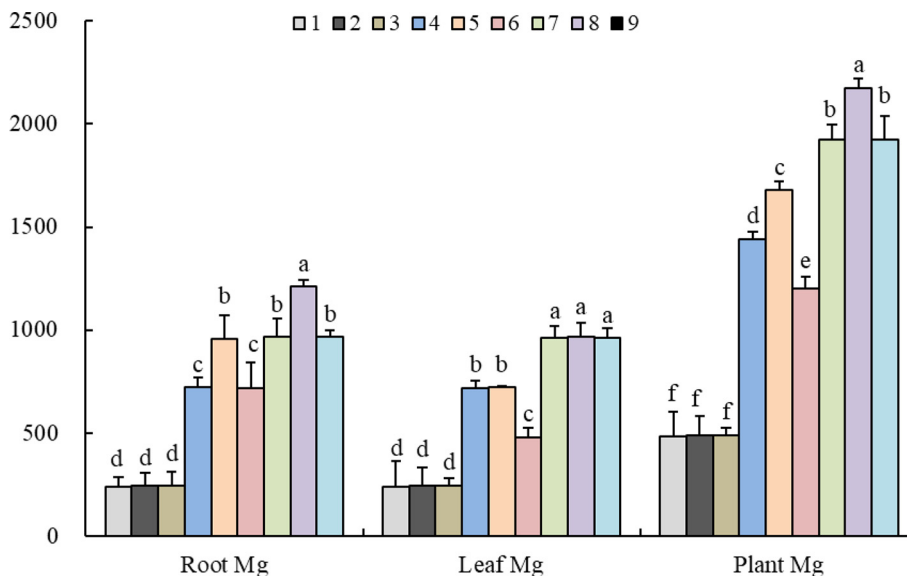


Fig. 2. Effect of nitrogen and magnesium application on magnesium contents in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in ppm d.wt. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

observed in radish pots fertilized with N and Mg application at a rate of $0.300 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil respectively while the least TSP (9.09 mg/g f.wt.) and TSS (1.39 mg/g f.wt.) were recorded under N_1Mg_1 shown in Fig. 4 and Fig. 5 respectively. The difference between different levels of nitrogen and magnesium in total soluble protein reaches a very significant level in root section of radish and similar trend was observed in radish plant (roots + leaves), while N_3Mg_1 and N_3Mg_3 levels of N and Mg were found significantly same in leaves section of radish. Similarly, the total soluble sugar in fleshy roots, leaves and plant (root + leaves) of radish under different treatments of nitrogen and magnesium were recorded significantly different from each other. The results described in Figs. 4 and 5, revealed that the

TSP and TSS increased significantly with increasing nitrogen and magnesium levels at a rate of $0.300 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil respectively while total soluble protein and total soluble sugar decreased significantly with increasing Mg level at a rate of $0.100 \text{ g Mg. kg}^{-1}$ soil. Nonetheless, the total soluble protein and total soluble sugar in radish were varied significantly by different treatments as follows: $N_3Mg_2 > N_3Mg_1 > N_3Mg_3 > N_2Mg_2 > N_2Mg_1 > N_2Mg_3 > N_1Mg_2 > N_1Mg_3 > N_1Mg_1$.

A highly significant influence was observed in ascorbic acid (Vitamin C) and crude fiber both in roots and leaves of radish affected by different levels of nitrogen and magnesium application. The ascorbic acid reached the maximum value of 1123 (ppm d.wt.) in root section, 935 (ppm d.wt.) in leaf section and 2058 (ppm d.

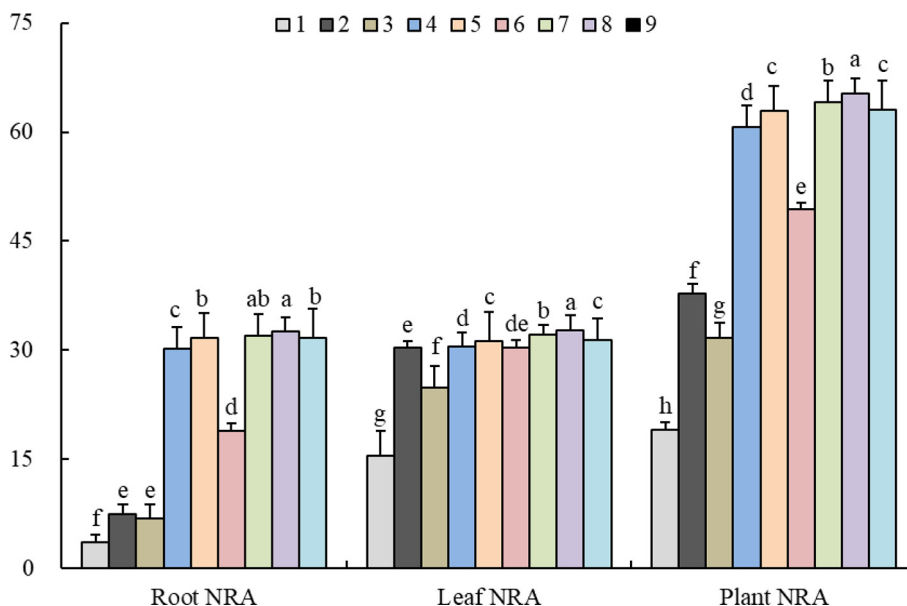


Fig. 3. Effect of nitrogen and magnesium application on nitrate reductase activity (NRA) in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in $\mu\text{mol NO}_2 \text{ g}^{-1} \text{ FW h}^{-1}$. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

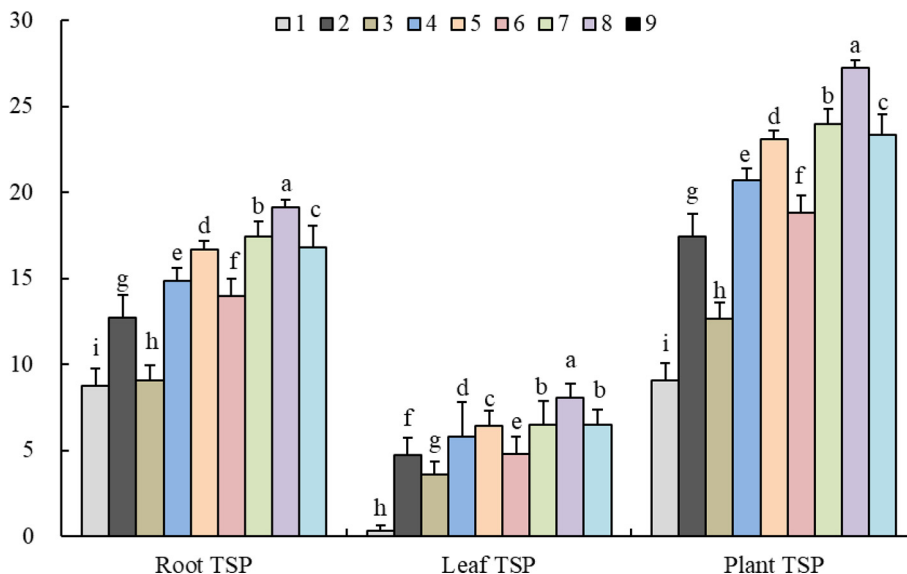


Fig. 4. Effect of nitrogen and magnesium application on total soluble protein (TSP) in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in mg/g f.wt. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

wt.) in plant (roots + leaves) of radish fertilized with N and Mg at the rate of $0.300 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil respectively while the least ascorbic acid was observed in N_1Mg_1 having no nitrogen and magnesium (Fig. 6). Vitamin C in roots, leaves and in radish plant (roots + leaves) increased significantly with increasing nitrogen and magnesium levels at a rate of $0.300 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil respectively while decreased significantly with increasing Mg level at a rate of $0.100 \text{ g Mg. kg}^{-1}$ soil. The response of ascorbic acid under different levels of N and Mg application was observed as follows: $N_3Mg_2 > N_3Mg_1 > N_3Mg_3 > N_2Mg_2 > N_2Mg_1 > N_2Mg_3 > N_1Mg_2 > N_1Mg_3 > N_1Mg_1$. Conversely, crude fiber in roots, leaves and in radish plant (roots + leaves) decreased significantly with increasing nitrogen level (N_1 , N_2 and N_3) while CF in roots, leaves and in radish plant (roots + leaves)

decreased significantly with Mg_1 and Mg_3 level but increased significantly at Mg_2 level ($0.050 \text{ g Mg. kg}^{-1}$ soil). The highest CF in radish roots (35%), leaves (31%) and plant (66%) were observed under nitrogen and magnesium application at a rate of $0.000 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil respectively while the least crude fiber in roots (14%) under N_3Mg_1 , leaves (10%) and plant (26%) were recorded under N_3Mg_3 (Fig. 7). Furthermore, highest crude fiber was found in roots (194%) as compared to leaves (183%) and the CF in roots were varied significantly by different treatments of nitrogen and magnesium as follows: $N_1Mg_2 > N_1Mg_3 > N_1Mg_1 > N_2Mg_2 > N_2Mg_3 > N_2Mg_1 > N_3Mg_2 > N_3Mg_3 > N_3Mg_1$, while in radish leaves as follows: $N_1Mg_2 > N_1Mg_1 > N_1Mg_3 > N_2Mg_2 > N_2Mg_1 > N_2Mg_3 > N_3Mg_2 > N_3Mg_1 > N_3Mg_3$.

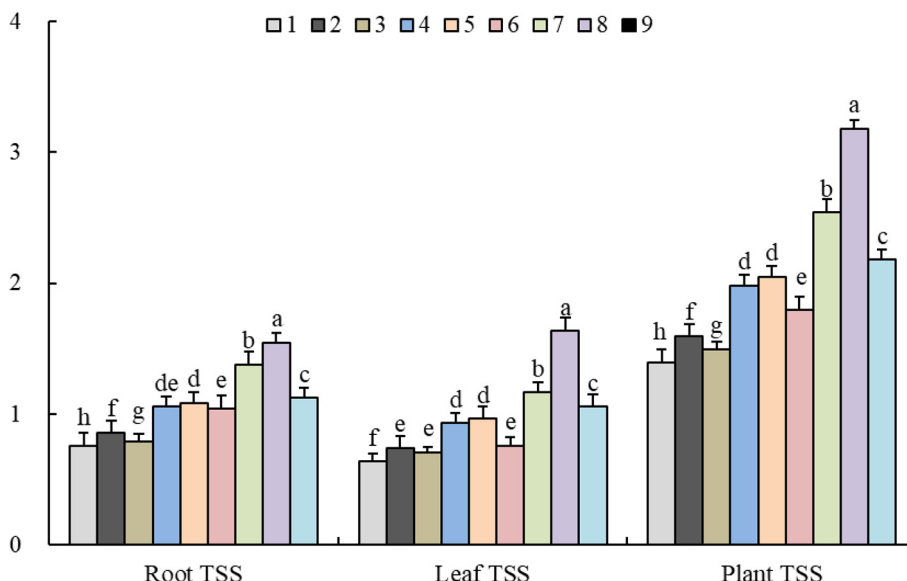


Fig. 5. Effect of nitrogen and magnesium application on total soluble sugar (TSS) in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in mg/g f.wt. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

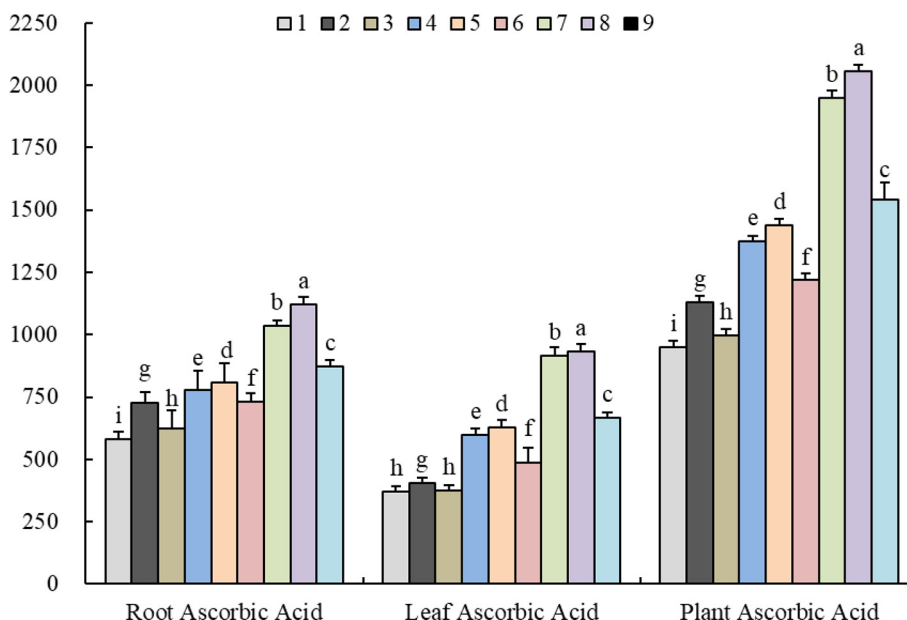


Fig. 6. Effect of nitrogen and magnesium application on ascorbic acid (Vitamin C) in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in ppm d.wt. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

4. Discussion

4.1. Radish growth and yield

In this research, the radish plant has positive relationship between nitrogen and magnesium uptakes for plant growth, and fresh and dry weight of roots and leaves. By increasing N and Mg level, not only growth increased but also yield of root and shoot increased because nitrogen fertilization increase vegetative growth (Jilani et al., 2010). The plant height, root length, shoot length, no of leaves, root and shoot diameters, and leaf length, leaf weight and

leaf chlorophyll concentrations; all these are indicators of growth. The highest root and shoot growth and yields were recorded in N_3Mg_2 (Table 2) at rate of $0.300 \text{ g N. kg}^{-1}$ soil and $0.050 \text{ g Mg. kg}^{-1}$ soil as compared to control (N_1Mg_1), and when we increased the Mg level to $0.100 \text{ g Mg. kg}^{-1}$ soil that declined the growth and yield of root and leaves of radish. All above discussed growth indicators positively increased at level N_3Mg_2 (Table 2) but decreased with decreasing N rates from 0.300 to 0.00 and Mg rates 0.050 to 0.00 g. kg^{-1} soil. While considering no. of leaves reaching their maximum range (38.00), leaf length (28.67 g) and leaf weight (19.00 g) of radish usually increased as compared N_1Mg_1 (control)

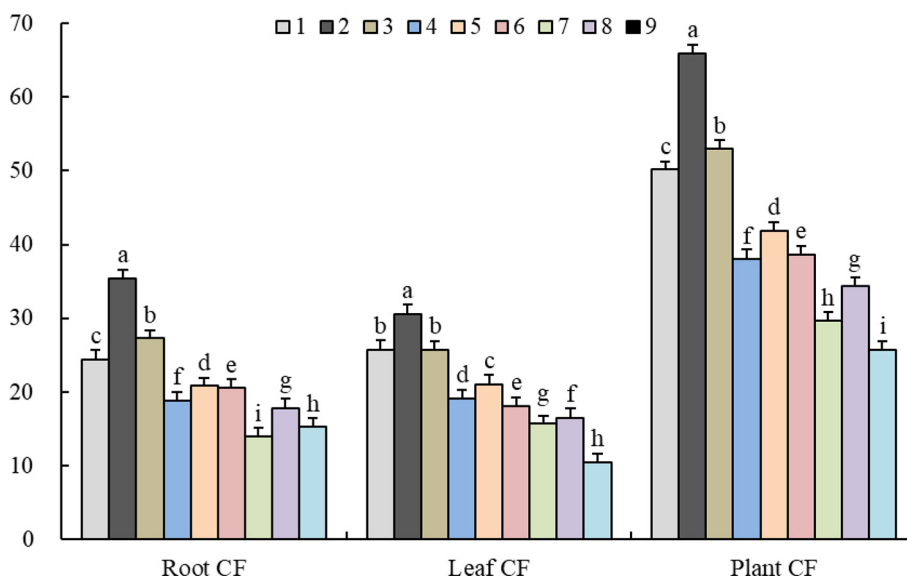


Fig. 7. Effect of nitrogen and magnesium application on crude fiber contents (CF) in roots, leaves and plant of radish. Each value represent the standard deviation ($n = 3$) and expressed in %. Mean values followed by different letters are significantly different at $P < 0.05$ according to LSD. The legends 1,2,3,4,5,6,7,8, and 9 represents N_1Mg_1 , N_1Mg_2 , N_1Mg_3 , N_2Mg_1 , N_2Mg_2 , N_2Mg_3 , N_3Mg_1 , N_3Mg_2 , and N_3Mg_3 respectively.

where minimum number of leaves (22.67), leaf length (11.83 g) and leaf weight (2.67 g) were observed. It was seen that N and Mg fertilizations significantly affected vegetative growth as well as yield of radish with increasing their rates for maximum growth and yield but the most suitable level of N and Mg with statistically and significantly that was N_3Mg_2 (Table 2). Other studies also reported that different N fertilization affects growth and yield characters (Poudel et al., 2018). Similar findings have been reported by Sandeep et al. (2014) and Khalid et al. (2015) in radish.

While considering root length, shoot length and plant height significantly resulted highest root length (36.33 cm), shoot length (27.67 cm) and plant height (64 cm) in radish as compared to N_1Mg_1 level of N and Mg application where lowest root length (27.33 cm), shoot length (11.00 cm) and plant height (38.33 cm) of radish were observed (Table 2), because of combinations of N and Mg fertilizer in N_3Mg_2 increased their growth in length. It was observed that maximum root length, shoot length and plant height followed by N_3Mg_2 (0.300 g N. kg^{-1} soil and 0.050 g Mg. kg^{-1} soil) as compared to control (N_1Mg_1). These results are also evidently in accordance with the findings of (Rampal et al., 2019). Significantly the maximum chlorophyll concentration was observed in leaves (40.93) when radish plant was treated with 0.300 g N. kg^{-1} soil and 0.050 g Mg. kg^{-1} soil. The lowest chlorophyll concentration of leaves was obtained in (N_1Mg_1). Chlorophyll concentration in leaves was varied according to different Mg levels from 0.00, 0.050 and 0.100 g. kg^{-1} soil. These findings are in conformity with the results of (Lakra et al., 2017; Dash et al., 2019) in radish. Similarly, significant results were observed in root diameter (23.67 cm) and shoot diameter (29.33 cm) when radish plant was treated with 0.300 g N. kg^{-1} soil and 0.050 g Mg. kg^{-1} soil (N_3Mg_2) as compared to control (N_1Mg_1) where root diameter (11.67 cm) and shoot diameter (12.67 cm) decreased significantly (Table 2). It was noted that with increasing N and Mg levels to 0.300 N and 0.050 Mg showed highly significant increasing root and shoot diameters as compared to N_1Mg_1 . Root and shoot diameter were significantly influenced among the different N and Mg levels because the root diameter affects to root yield and shoot diameter affects the shoot yield when increase their diameter. Similar findings of radish growth and yield have been reported (Yuan et al., 2014; Khalid et al., 2015).

The fresh and dry weight of root, fresh and dry weight of shoot, plant fresh and dry weight was significantly influenced by the application of various nitrogen and magnesium treatments (Table 3). These results are also consistent with the results of (Kushwah et al., 2020). These showed varied findings with different N and Mg rates of fertilizations in yield parameters. The highest root fresh weight (734 g) and root dry weight (640 g) were recorded when radish was fertilized at 0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil while lowest root fresh weight (99 g) and root dry weight (102 g) of radish were noticed under N_1Mg_1 level (Table 3). Similarly, the maximum shoot fresh weight (314 g) and shoot dry weight (104 g) of radish were observed under N_3Mg_2 (0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil) treatment while minimum shoot fresh weight (38 g) and shoot dry weight (15 g) were recorded in N_1Mg_1 (control). The results showed that the plant fresh weight (1048 g) and plant dry weight (745 g) yields of radish were significantly increased under N_3Mg_2 level as compared to control (N_1Mg_1) where plant fresh weight (138 g) and plant dry weight (118 g) yields of radish decreased significantly (Table 3). The increased fresh and dry weight of root and shoot was because of higher N and Mg uptake that greatly increased root and shoot (fresh and dry weights) and total plant fresh and dry weight that turned higher yields in radish. Similar findings also reported in radish growth and yields (Baloch et al., 2014; Kiran et al., 2016).

Total nitrogen uptake in radish root and leaves showed significant correlation with root and shoot yield at every nitrogen and Mg level (Fig. 1). Root and shoot yields have direct relationship with every increasing level of nitrogen and magnesium. These relationships significantly showed that total nitrogen has positive and linear relation with the plant fresh and dry weight yields. The highest total N uptake in roots (3.02%) and in leaves (2.44%) were recorded when radish was fertilized at 0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil while lowest total N uptake in radish roots (1.62%) and leaves (0.73%) of radish were noticed under N_1Mg_1 level (Fig. 1). It has been seen that fertilizer nitrogen application to radish that interacts with the soil and plant that increase the total nitrogen uptake in roots and leaves (Zheng et al., 1994). It was found that the high NO_3 accumulation in radish roots and leaves due to higher level of nitrogen fertilizer levels and reduced radish growth and yields as reported by previous studies (Elia et al., 1998). The higher levels of nitrogen not only reduced the growth and yields but also have detrimental effects on radish quality (Ikemoto et al., 2002; Ishiwata et al., 2002). Similarly, the maximum magnesium concentration in roots (1210%) and leaves (965%) of radish were observed under N_3Mg_2 (0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil) treatment while minimum magnesium concentration in roots (242%) and leaves (240%) were recorded in N_1Mg_1 (control). The low level of Mg as in N_1Mg_1 resulted low plant growth and yield and effectively reduced chlorophyll production and these results are also confirmed (Samborska et al., 2018; Ortas 2018; Saghaiesh et al., 2019; Farhat et al., 2016). Hence, the significant level that increased magnesium concentration in radish roots and leaves was N_3Mg_2 (Fig. 2) as compared to N_1Mg_1 level. The maximum NR activity $33(\mu\text{mol } NO_2 \text{ g}^{-1} \text{ FW h}^{-1})$ in roots and $32.77 (\mu\text{mol } NO_2 \text{ g}^{-1} \text{ FW h}^{-1})$ in leaves were recorded when radish was fertilized at 0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil while lowest NR activity $3.55(\mu\text{mol } NO_2 \text{ g}^{-1} \text{ FW h}^{-1})$ in roots and $15.51 \text{ NRA} (\mu\text{mol } NO_2 \text{ g}^{-1} \text{ FW h}^{-1})$ in leaves of radish were noticed under N_1Mg_1 level (Fig. 3). The treatment of N_3Mg_2 was statistically significant as compared to control N_1Mg_1 and other N and Mg levels. But the higher range 0.300 g N. kg^{-1} soil + 0.100 g Mg. kg^{-1} soil led to decline NR activity affecting NO_3^- accumulation in radish. There was higher NO_3^- accumulation in radish leaves as compared to roots and NO_3^- accumulation affected due to declined NR activity. Hence, it was noted a linear and negative relationship between NO_3^- and NR activity in radish roots and leaves as reported by (Hu et al., 1992). Other findings by (Matt et al., 2001; Scheible et al., 1997) investigated the relationship between NO_3^- and NR activity in radish.

4.2. Radish nutritional quality

The contents of soluble protein, soluble sugar and ascorbic acid significantly influenced by the application of various nitrogen and magnesium treatments (Figs. 4, 5 and 6). Significantly maximum soluble protein (19 mg/g f.wt) in roots; in leaves (8.09 mg/g f. wt), soluble sugar (1.55 mg/g f.wt) in roots; in leaves (1.63 mg/g f.wt) and ascorbic acid (1123 ppm d.wt.) in roots; in leaves (9345 ppm d.wt.) of radish were observed under N_3Mg_2 (0.300 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil) while minimum soluble protein (8.78 mg/g f.wt) in roots; in leaves (0.31 mg/g f.wt), soluble sugar (0.76 mg/g f.wt) in roots; in leaves (0.64 mg/g f.wt) and ascorbic acid (580 ppm d.wt.) in roots; in leaves (370 ppm d. wt.) of radish were recorded in N_1Mg_1 (control) level. Nitrogen and magnesium contents enhance photosynthesis and increase accumulation of carbohydrates but excessive nitrogen and magnesium decreases not only growth and yield but also quality, reduced photosynthesis and carbohydrates (Foyer et al., 1998) that result decreased soluble sugar, soluble protein and ascorbic acid in radish roots and leaves. Further investigations reported result that low

nitrogen availability reduced carbohydrate accumulation in radish roots and leaves (Noguchi and Terashima, 2006).

The higher nitrogen assimilation in radish roots and leaves indicated much more photosynthesis used in nitrogen assimilation and the crude fiber contents decreased with increase of different levels of nitrogen and magnesium (Fig. 7). There was only one treatment that showed increasing trend of crude fiber (35%) in roots and (31%) in leaves of radish under N_1Mg_2 (0.000 g N. kg^{-1} soil + 0.050 g Mg. kg^{-1} soil). While, all other levels of nitrogen and magnesium the crude fiber contents reduced (Fig. 7). Goyeneche et al. (2015) reported proximal composition of crude fiber in roots and leaves of radish. To determine quality of vegetables especially in radish the crude fiber contents influenced by variety of factors as different levels of nitrogen (Shou et al., 2007). Similar results were in conformity with the findings of Kopta and Pokluda, (2013) in radish crop.

5. Conclusion

Vegetables are important agricultural products indispensable to people's lives, and the vegetable industry is an important industry related to the national economy and people's livelihood. Radish occupies an important position in the production and consumption of vegetables globally. Mineral fertilizer application has brought about high radish production, therefore the nutrient management of radish is very important for the rational use of nutrients in our country and for coordination of economic, agronomic and environmental benefits. The different levels of nitrogen and magnesium application affected significantly on the growth, yield and nutrient contents in radish. The results of the study demonstrated that with the increase of nitrogen fertilizer application, the growth dynamics, yield and nutrient contents in roots and leaves of radish were increased at a range of 0.00 g N. kg^{-1} soil to 0.300 g N. kg^{-1} soil while the growth, yield and nutritional quality responses of radish were increased with the increase of magnesium fertilizer application at a range of 0.00 g Mg. kg^{-1} soil to 0.050 g Mg. kg^{-1} soil and then decreased gradually at a level of 0.100 g Mg. kg^{-1} soil, while in contrast, the crude fiber contents in roots and leaves of radish were decreased significantly with increasing nitrogen and magnesium levels but crude fiber contents in radish increased significantly when magnesium was applied at a rate of 0.050 g Mg. kg^{-1} soil. Furthermore, the highest growth, yield and quality of radish were observed when N and Mg were applied at a rate of 0.300 g N. kg^{-1} soil and 0.050 g Mg. kg^{-1} soil respectively while least results were observed under control level. Though, the growth dynamics and yields of radish Though, there is no statistically significant difference in the growth and yields of radish were observed among the different magnesium application levels but the average results showed an increasing trend, and the nutrient contents of radish were significantly affected by magnesium application which became the biological basis for the proper use of magnesium fertilizer. Furthermore, the maximum plant height, number of leaves, leaf weight, chlorophyll contents, yield and biomass, total soluble protein, total soluble sugar and vitamin C both in roots and leaves of radish were observed in pots receiving N followed by Mg as compared to pots with no N followed by no Mg, revealing that nitrogen is the key nutrient affecting growth, yield and quality of radish followed by Mg.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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