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Equilibrium Content between Nitrogen and Phosphorus for Lettuce (*Lactuca sativa* L.) Grown in A Clay Soil

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THIS study aims to investigate the effect of different nitrogen concentrations (60, 120 and 180 mg L^{-1}) applied in the form of ammonium nitrate (NH_4NO_3) through fertigation and, also, phosphorus concentrations (15, 35 and 55 mg L^{-1}) in the form of phosphoric acid (H_3PO_4), individually or in combination with each other,on the growth parameters and yield of lettuce plants (*Lactuca sativa* L.), as well as nitrate accumulation in plant tissues. The investigations were conducted under the field conditions during the two growing seasons of 2019/2020 and 2020/2021 at the experimental farm of Dokki site, Giza Governorate, Egypt, following a split plot design. Obtained results indicated that increasing N supplies up to 180 mg L^{-1} led to concurrent increase in the vegetative growth characters (i.e., plant height, stem diameter, number of leaves per plant and chlorophyll content) of lettuce plants. While the lowest growth and productivity of plants were obtained by applying 60 mg N L^{-1}. Regarding the effects of P additions, increasing P supply up to 55 mg L^{-1} increased the growth and productivity of plants during both studied seasons. Interaction effect between N and P levels indicated that 180 mg N L^{-1} combined with 55 mg P L^{-1} gave the highest lettuce productivity followed by 180 mg N L^{-1} combined with 35 mg P L^{-1}. The weight of lettuce head took the same trend of vegetative growth. The chemical analyses revealed that increase N dose led to increase the content of N, K, Ca and Mg as well as N-NO_3^-in plant tissues. Increase P level led to increase the P content. Finally, increase P level led to decrease N-$NO_3^-$and transformation rate of nitrate in plant tissues.

Keywords: Fertigation, Nitrogen, Phosphorus, Lettuce yield, Nutrient equilibrium, Nitrate accumulation.

Introduction

Excess N fertilization may decrease plant productivity and, also, may harm human health through accumulation of nitrate in the edible plant parts (Parente et al., 2006; Farag et al., 2013 and El-Dissoky, 2019). Leafy vegetable crops especially lettuce may accumulate NO_3^- ions when applying N in high doses (Prasad and Chetty, 2008), despite its short cultivation cycle. Moreover, NO_3^- accumulation in lettuce leaves may have adverse impacts on climate changes and increase greenhouse gas emissions (Farag and Abd-Elrahman, 2016; Abd-Elrahman & Gad-Elmoula, 2017 and Elbasiouny and Elbehiry, 2019). Therefore, application of N fertilization in lettuce fields should consider not only farming economics but also the market preference and human health as well as environmental hazards issues (Schenk, 2006). Low N inputs induce metabolic imbalance within plants and, also, limits the synthesis of amino acids and proteins, thereby affect negatively on photosynthesis, growth, and chemical composition of the plant tissue (Liao et al., 2019). This may lessen plant growth especially in early growth stage and, also, delay flowering (Burns, 1996 and Moursy et al., 2019). Thus, timing and the dose of N-application may have direct impacts on fruit yield quantity and quality (Heidari and Mohammad, 2012).

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Phosphorus, as an essential nutrient for all higher plants, is playing a vital role in enhancing plant growth and increasing yield with better quality (Khalifa, 2019). It is involved in many key plant functions, including photosynthesis, energy transfer molecules (ATP, ADP and AMP), transformation of sugars and starches, nutrient movement within the plant tissues and transfer of genetic characteristics from one generation to the next (Hammouda et al., 2019).

Studies had focused on the effect of applying different levels of N, forms, and the time and way of application to leafy crops, as well as nitrate accumulation (Corradini et al., 2018 and Tabaglio et al., 2020). Less studies had pointed to the effects of P on the growth and yield of leafy crops and its effect on NO_3^- accumulation rate inside the plants' tissues (Sadeghi et al., 2009). Therefore, further studies are needed in this concern. Ahmed et al. (2000) found significant reductions in nitrate contents inside plant tissues due to an increase in P fertilization rate. Inorganic P inside the plant is necessary for the metabolism and storage of nitrate, but high concentrations of it inhibit enzyme reactions, accelerate the growth, and the growth is accompanied by a decrease in nitrate uptake and accumulation (Buwalda and Warmenhoven, 1999).

Plant growth in the presence of N and P being considered most important because of their function role inside the plant and the large amount required for proper plant growth. Although soil provides most of these nutrients, reserves are limited, and fertilizer additions are necessary to maintain adequate nutrition. The use of fertilizers in crop production is critical to improve production efficiency for sustainable feeding of an ever-increasing population (Du et al., 2009; Sarkar et al., 2021). Thus, the current study aimed to investigate the proper quantity and equilibrium between N and P for good and healthy production of lettuce plants grown on a clay soil.

Materials and Methods

Experimental site

A field experiment was carried out during two successive seasons of 2019/2020 and 2020/2021 at the experimental farm of Central Laboratory for Agricultural Climate, Dokki, Agricultural Research Center, Giza governorate, Egypt. The coordinate of the farm is 30.04588 N, and 31.20463 E. Table 1 illustrates the climatic conditions for the farm location during the experiment. Data were collected from an automated weather station installed in the farm location. The investigated soil was a clayey one, *Vertic Torrifluvents* (according to Soil Survey Staff, 2010), and its physico-chemical properties were determined, before cultivation, by the standard methods outlined by Cottenie et al. (1982) and the obtained results are presented in Table 2.The Nile River water is the source of irrigation water; the EC of water was 0.38 dS m^{-1}. Chemical composition of the water used for irrigation are presented in Table 3.

Experimental design and procedures

The experimental design was a split plot design, included three N levels, i.e., 60, 120 and 180 mg L^{-1} located at the main plots as well as three P levels, i.e., 15, 35 and 55 mg L^{-1} which located as sub-plots. These applications were applied through fertigation system either individually or in combination with each other. Nitrogen was added in the form of ammonium nitrate (NH_4NO_3, 33% N); P levels in the form of P_2O_5 was applied as phosphoric acid- 85% H_3PO_4 (61% P_2O_5). Seeds of iceberg lettuce (*Lactuca sativa* var. *capitata* L.) cv. Chianti were sown on 13th and 16th September in polystyrene trays. Dates of transplanting were November 2nd and 5th of 2019 and 2020, for the first and the second seasons, respectively. The plants were cultivated in raised beds with 1 m width and 40 m length. Each bed represented one of the N levels (i.e., 60, 120 and 180 mg L^{-1}). Each raised bed contained the different P levels (i.e., 15, 35 and 55 mg L^{-1}). The experimental plot area was 120 m^2 and all treatments were conducted in triplicates. Fertilizer tank was used for injecting the different N and P levels.In addition, each raised bed contained two rows of lettuce irrigated by one lateral dripper with discharge 4 L h^{-1}. The in-row distance between each two plants is 30 cm. Common cultural practices were used for lettuce production according to recommended practices for lettuce in the commercial fields.

Measurements

Samples of three plants were randomly harvested at 50 days from planting to determine their fresh and dry weights, as well as plant height, stem diameter and number of leaves per plant. Total chlorophyll was also estimated in the plant samples as a SPAD value as reported by Minolta (1989). The yield of lettuce was harvested after 70 days from transplanting. Total dry weight was determined after oven-drying the samples at 65 ºC for 48 hr. Dried plant leaves were digested in H_2SO_4/H_2O_2 mixture according to the method described by Chapman and Pratt (1961), and the macro-nutrient, i.e., N, N-NO_3^-, P, K, Ca and Mg were determined.Total N and N-NO_3^- were determined using Kjeldahl method according to the procedure outlined by Chapman and Pratt (1961). Phosphorus content was determined using Spectrophotometer according to Watanabe and Olsen (1965). Potassium content was measured using Flame photometer as outlined by Chapman and Pratt (1961). Calcium and magnesium were determined by EDTA according to the method that described by Derderian (1961).

Accumulation rate (%) of nitrate was computed as follows:

$$\text{Accumulation rate, \% (Transformation rate)} = \frac{\text{Accumulated nitrate in plant (mg kg}^{-1}\text{)}}{\text{Total absorbed N by plant (mg kg}^{-1}\text{)}} \times 100$$

Statistical analysis

Analysis of data was done using ANOVA program for statistical analysis. The differences among means for all traits were tested for significance at 5% level of probability using Duncan's multiple range test (SAS, 2006).

TABLE 1. Meteorological data for Dokki site, Egypt during lettuce growing seasons of 2019/2020 and 2020/2021

	Air Temp. (°C)		RH (%)	Precipitation	Wind Speed	Soil Temp.	ET_o (mm)
	Max.	Min.	Avg.	Sum. (mm)	Avg. (m s^{-1})	Avg. (°C)	Avg.
				1st season			
Nov. 2019	28.9	10.8	57.9	11.6	0.30	21.7	3.20
Dec. 2019	21.6	6.60	56.5	10.7	0.50	16.5	2.60
Jan. 2020	17.8	4.20	59.6	3.20	0.50	13.4	2.10
Feb. 2020	19.6	5.70	57.2	6.90	0.40	15.2	2.40
				2nd season			
Nov. 2020	27.6	10.3	58.2	7.40	0.40	20.2	3.10
Dec. 2020	23.1	8.80	58.8	6.00	0.20	16.8	2.80
Jan. 2021	18.3	5.50	58.8	3.80	0.40	16.4	2.20
Feb. 2021	20.9	5.50	57.8	1.60	0.50	16.6	2.50

TABLE 2. Some physical and chemical properties of the experimental soil (0-20cm)

Physical Property					Water status, %			
Sand, %	Silt, %	Clay, %	Textural class	BD Mg m^{-3}	SP	FC	WP	AW
15.7	24.7	59.6	Clay	1.36	92.4	55.3	30.1	25.2
Chemical property								
pH (Soil paste)	EC_e dS m^{-1}	Soluble ions, mmol$_c$ L^{-1}						
		Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}
7.43	2.74	11.2	7.88	11.9	5.96	7.10	13.2	14.2

Carbonate ions were not detected. BD means bulk density, SP means saturation percentage, FC means field capacity, WP means welting point, and AW means available water.

TABLE 3. Chemical composition of the water used for irrigation.

pH	EC_w dS m^{-1}	Soluble ions, meq L^{-1}							
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
7.23	0.38	1.55	1.08	0.98	0.19	n.d.*	2.08	1.25	0.47

*n.d. means not detected.

Results and Discussion

Vegetative growth characters

Data in Table 4 showed the vegetative characteristics of lettuce under different levels of N and P during the two studied seasons. Regarding the N level data indicated that the highest N level (180 mg L^{-1}) gave the highest lettuce growth during the two seasons. The treatment of 120 mg N L^{-1} came in the second order, by about 6.90, 7.84, 8.82, 3.31, 9.40, and 7.66% reduction during the first season, and 9.34, 11.2, 10.1, 3.03, 7.22, and 8.19% reduction during the second season, as compared to the values given by applying the treatment of 180 mg N L^{-1} for the studied vegetative growth parameters, i.e., fresh and dry weights, plant height, stem diameter, number of leaves per plant, and chlorophyll content, respectively. While the lowest N level gave the lowest lettuce growth.

Referring to the different levels of P for lettuce crop which are cultivated in clay soil, increasing P level up to 55 mg L^{-1} led to concurrent increase in the vegetative growth during both studied seasons. The interaction effect showed that the highest N level combined with different P levels led to increase vegetative growth. The 180 mg L^{-1} of N combined with 55 mg L^{-1} of P gave the highest vegetative growth during both studied seasons followed by 180 mg L^{-1} of N combined with 35 mg P L^{-1}, while the lowest interaction value was obtained by the lowest N level (60 mg L^{-1}) combined with different P levels. These results agreed with those obtained by Johnstone et al. (2005); Hoque et al. (2010); Farag et al. (2013); Djidonou and Leskovar (2019) about the effect of N and P fertilizers on the vegetative growth characters of lettuce plants.

Yield

Regarding the N level treatments, 180 mg N L^{-1} produced the significant highest lettuce heads during the two seasons. The treatment of 120 mg N L^{-1} came in the second order, while applying 60 mg N L^{-1} produced the lowest lettuce yield (Table 4). Regarding P levels (Table 4), the obtained results revealed that 55 mg P L^{-1} gave the highest lettuce productivity in the two growing seasons. Lettuce production is reduced with reducing P concentration in the fertigation system. The lowest lettuce heads yield was obtained by 15 mg L^{-1} of P during the two studied seasons. Interaction effect between N and P levels (Table 4) was significant during the two investigated growing seasons. The lowest lettuce head was obtained by the lowest N level (60 mg L^{-1}) combined with different P levels. Increasing N levels from 60 to 120 mg L^{-1} led to increase yield sharply especially with moderate (35 mg L^{-1}) or high (60 mg L^{-1}) P levels. The highest N level (180 mg L^{-1}) gave the highest lettuce heads combined with different P levels.

Nitrogen is an essential nutrient for plant growth and development during cell division and enlargement phases of growth. Razaq et al. (2017) reported that N accelerate vigorous growth and its low rate than plant need leads to decline growth and low production. Saleh et al. (2016) stated that plant productivity increased as N dose increased up to 360 kg ha^{-1}. The better yield under higher supply of N was probably due to increasing the photosynthetic and uptake rates, which leads to an increase in the vegetative growth and heads yield of lettuce (Sarkar et al., 2021). With higher N rates, growth and yield increased due to dependent relationship between N and carbohydrates exist inside the plant (Djidonou and Leskovar, 2019) which led to increase the content of carbohydrates and proteins that considered as the final products of photosynthesis and metabolic activities.

Lettuce showed a pronounced yield and quality as affected by P fertilizer rates (Johnstone et al., 2005). Lettuce was found to have higher requirements of P fertilizer than most other crops across different soil textures (Hoque et al., 2010). Inadequate supply of P led to slow down the growth of plants by reducing the water uptake of the root system. The role of P in enhancing root growth, which in turn improves the ability of crops for phosphate acquisition. Phosphorus application in green beans is known to have a positive effect on enhancing root proliferation and thus enhancing soil water and nutrients uptake (Emam et al., 2018).

TABLE 4. Effect of fertigation by different levels of N and P, and their interaction, on vegetative growth characters and yield of lettuce during the two studied seasons of 2019/2020 and 2020/2021

Variable	P1	P2	P3	Mean	P1	P2	P3	Mean
1st season					**2nd season**			
Fresh weight (g plant^{-1})								
N1	318h	336g	354f	336C	351f	369e	377e	366C
N2	426e	486c	545b	486B	445d	506c	563b	505B
N3	465d	547ab	554a	522A	503c	571b	596a	557A
Mean	403C	457B	485A		433C	482B	512A	
Dry weight (g plant^{-1})								
N1	3.60g	4.75e	5.11d	4.49C	4.03g	4.17f	4.20f	4.13C
N2	3.75g	5.37c	5.71b	4.94B	5.03e	5.66d	5.95c	5.55B
N3	3.95f	6.02a	6.12a	5.36A	5.69d	6.38b	6.67a	6.25A
Mean	3.77C	5.38B	5.65A		4.91C	5.41B	5.61A	
Plant height (cm)								
N1	16.1g	16.3fg	16.5f	16.3C	17.0g	17.9f	18.2f	17.7C
N2	18.0e	18.5d	19.2c	18.6B	18.9e	19.7d	20.6c	19.7B
N3	19.4c	20.5b	21.2a	20.4A	21.5b	21.6b	22.6a	21.9A
Mean	17.8C	18.4B	19.0A		19.1C	19.7B	20.4A	
Stem diameter (cm)								
N1	11.4h	11.6h	11.9g	11.6C	12.4h	12.7g	12.9g	12.7C
N2	13.5f	14.7d	15.7b	14.6B	14.8f	16.1d	17.2b	16.0B
N3	14.0e	15.2c	16.0a	15.1A	15.4e	16.6c	17.5a	16.5A
Mean	13.0C	13.8B	14.5A		14.2C	15.1B	15.9A	
No. of leaves per plant								
N1	16.8i	17.1h	19.0g	17.6C	18.3g	19.4f	20.4e	19.4C
N2	22.5f	23.5e	26.1c	24.1B	23.9d	25.3c	28.0b	25.7B
N3	24.3d	26.6b	29.0a	26.6A	25.3c	27.7b	30.1a	27.7A
Mean	21.2C	22.4B	24.7A		22.5C	24.1B	26.2A	
Chlorophyll (SPAD)								
N1	26.0g	27.1f	27.4f	26.9C	28.2g	29.8f	29.8f	29.3C
N2	38.1e	39.7d	41.8c	39.8B	36.9e	42.9c	44.7b	41.5B
N3	42.3bc	42.9b	44.0a	43.1A	42.1d	46.9a	46.6a	45.2A
Mean	35.5C	36.6B	37.7A		35.7C	39.9B	40.3A	
Yield (g plant^{-1})								
N1	485h	505g	526f	506C	527h	547g	565f	546C
N2	636e	744c	824b	735B	687e	804c	893b	795B
N3	699d	818b	869a	796A	751d	886b	945a	861A
Mean	607C	689B	740A		655C	746B	801A	

Note: N1 (60 mg L^{-1}), N2 (120 mg L^{-1}) and N3 (180 mg L^{-1}) in the form of NH_4NO_3; and P1 (15 mg L^{-1}), P2 (35mg L^{-1}) and P3 (55 mg L^{-1}) in the form of H_3PO_4, added to the soil by fertigation system. Different letters mean significant at 5% level.

Nutrient content in leaves

Regarding to the effect of N levels, data in Table 5 showed that using 180 mg N L^{-1} led to increase the content of N, P, K, Ca and Mg significantly in the dry weight of lettuce leaves followed by 120 mg N L^{-1} with significant difference between them. The lowest content of the studied macro-nutrients was obtained by applying 60 mg N L^{-1}.

Data in Table 5, also, showed the effect of different P levels on the content of the studied macro-nutrients of lettuce leaves during the two investigated seasons. The highest content was observed by applying 55mg L^{-1} followed by 35 mg L^{-1} P during both seasons. While the lowest ones were obtained by applying 15 mg P L^{-1}. Regarding the interaction effect between N and P levels, data showed that using 180 mg N L^{-1} combined with 55 mg P L^{-1} increased the plant content of the studied macro-nutrients. While the lowest ones preceded by applying 60 mg N L^{-1} with 15 mg P L^{-1}. Similar results were obtained by Farag et al. (2013) who stated that increase N dose for lettuce led to increase the plants uptake from N, P, K, Ca and Mg through enhancing the plants metabolism and then increase plant needs for absorb more nutrients. On the other hands, P played a positive effect on enhancing root proliferation and thus enhancing nutrients uptake (Emam et al., 2018).

Nitrate accumulation

Regarding nitrate content, data indicated that increased N level led to concurrent increase in nitrate content during both seasons (Table 5). While P had another trend, increasing P level up to 55 mg L^{-1} led to decrease nitrate content in produced lettuce heads. Many researchers have demonstrated that applying N fertilizers increased accumulation of NO_3^- in plant leaves (Hoque et al., 2010; Corradini et al., 2018; Tabaglio et al., 2020). The European Union set limits from 3500 to 4500 mg NO_3^- kg^{-1} of lettuce fresh leaves for the winter season and 2500 mg NO_3^- kg^{-1} for the summer crops (Anon, 2011). However, the EU set the acceptable daily intake of NO_3^- at 0-3.7 mg kg^{-1} bodyweight (Anon, 2011). According to these limits, NO_3^- concentrations in lettuce leaves were sufficient. But the threat is found by continuing application with excess amount of N fertilizers, which will certainly lead to nitrate pollution.

These results agreed with those obtained by Wang et al. (2008) who stated that higher N doses increased the N-NO_3^- concentration in lettuce tissues. Generally, high N-NO_3^-accumulation in leafy vegetables is expected due to harvesting at the vegetative growth stage. As the concentration of P increased, the nitrate levels in lettuce leaves decreased. Phosphorus levels are linked to nitrate uptake and metabolism. Increasing P concentration in plant cells led to significant increase in nitrate reductase activity and then decline of nitrate content (Buwalda and Warmenhoven, 1999; Ahmed et al., 2000).

Accumulation rate of NO_3^- in lettuce leaves as influenced by N and P levels under fertigation system and their interaction are illustrated in Figs. 1, 2 and 3. Despite the similarity of the applied different N levels in total NO_3^- accumulation in lettuce leaves, tending to relatively reduce accumulation with applying N1 (60 mg L^{-1}) without any significant difference between this application and the other applications of N level. Logically, supply lettuce plants with N; increases N accumulation in plant leaves (Fig. 1).

Regarding the P levels, the rate of NO_3^- accumulation associated with application of P1 (15 mg L^{-1}) was higher than the other levels of applied P, with significant difference between them (Fig. 2). It may be due to that P in high levels increases nitrate reductase activity, so, decreases NO_3^- accumulation inside the plant tissues (Buwalda and Warmenhoven, 1999; Ahmed et al., 2000). However, the difference in NO_3^- accumulation due to the interaction between N and P levels (Fig. 3) were significant in most of cases, with high rate that achieved by the treatment of N3×P1, on the other hand, the low rate was achieved by N1×P3 treatment.

TABLE 5. Effect of fertigation by different levels of N and P, and their interaction, on nutrient content of lettuce leaves during the two studied seasons of 2019/2020 and 2020/2021

Variable	P1	P2	P3	Mean	P1	P2	P3	Mean
1st season					**2nd season**			
N (g kg^{-1})								
N1	18.3g	19.8f	20.5f	19.5C	18.8g	18.9g	20.5f	19.4C
N2	24.3e	24.8de	25.4d	24.8B	24.1e	25.9d	25.8d	25.3B
N3	27.9c	29.5b	30.9a	29.4A	28.7c	29.1b	31.5a	29.8A
Mean	23.5C	24.7B	25.6A		23.9C	24.6B	25.9A	
P (g kg^{-1})								
N1	2.40f	3.60d	4.01bc	3.34C	2.45f	3.58d	3.99bc	3.34C
N2	2.6ef	3.87c	4.67a	3.71B	2.60f	3.82cd	4.73a	3.72B
N3	2.81e	4.14b	4.83a	3.93A	3.02e	4.22b	4.78a	4.01A
Mean	2.60C	3.87B	4.50A		2.69C	3.87B	4.50A	
K (g kg^{-1})								
N1	26.2f	27.8ef	28.4de	27.5C	27.5d	26.7d	28.4c	27.5B
N2	29.8cd	32.7b	31.8b	31.4B	29.0c	31.7b	32.6ab	31.1A
N3	31.6bc	35.5a	36.9a	34.7A	31.7b	33.6a	28.4c	31.2A
Mean	29.2B	32.0A	32.4A		29.4B	30.7AB	29.8A	
Ca (g kg^{-1})								
N1	16.3e	16.8e	17.2de	16.8B	18.1c	18.5bc	18.8b	18.5C
N2	16.6e	17.9d	18.5cd	17.7B	19.1b	20.8a	21.3a	20.4B
N3	19.4bc	20.5b	24.0a	21.3A	21.6a	21.5a	22.2a	21.8A
Mean	17.4B	18.4B	19.9A		19.6B	20.3A	20.8A	
Mg (g kg^{-1})								
N1	2.42c	4.26b	4.31b	3.66C	3.53d	3.62d	3.77d	3.64C
N2	4.44b	4.71b	4.86ab	4.67B	4.38c	4.84b	4.73b	4.65B
N3	4.91ab	5.07a	5.69a	5.22A	4.88b	4.87b	5.67a	5.14A
Mean	3.92B	4.68A	4.95A		4.26B	4.45B	4.72A	
NO_3^- (mg kg^{-1})								
N1	662g	582h	533i	592C	676g	569h	546i	597C
N2	923c	805e	720f	816B	895c	816e	699f	803B
N3	1214a	1015b	824d	1018A	1237a	990b	849d	1026A
Mean	933A	801B	693C		936A	791B	698C	

See footnotes of Table 4.

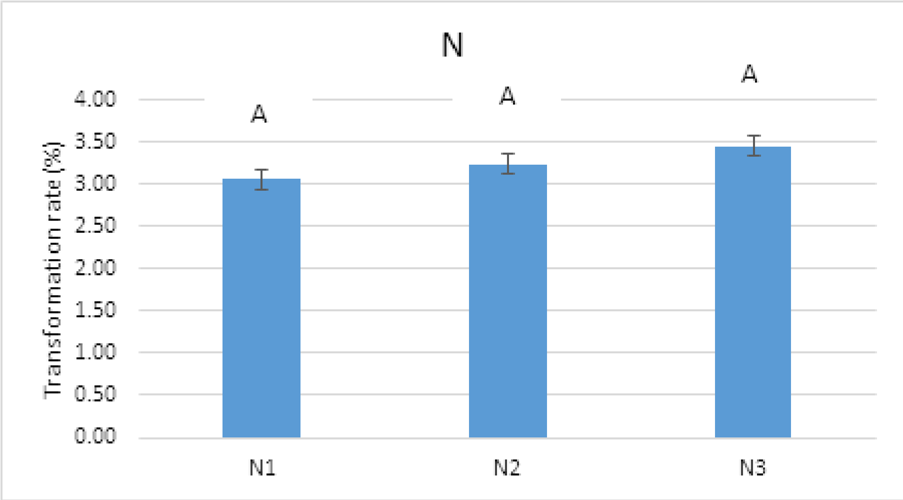

Fig. 1. Effect of N levels on NO_3^- transformation rate in lettuce (the average of mean values of the two studied seasons)

Note: N1 (60 mg L^{-1}), N2 (120 mg L^{-1}) and N3 (180 mg L^{-1}) in the form of NH_4NO_3, added to the soil by fertigation system. Different letters mean significant at 5% level.

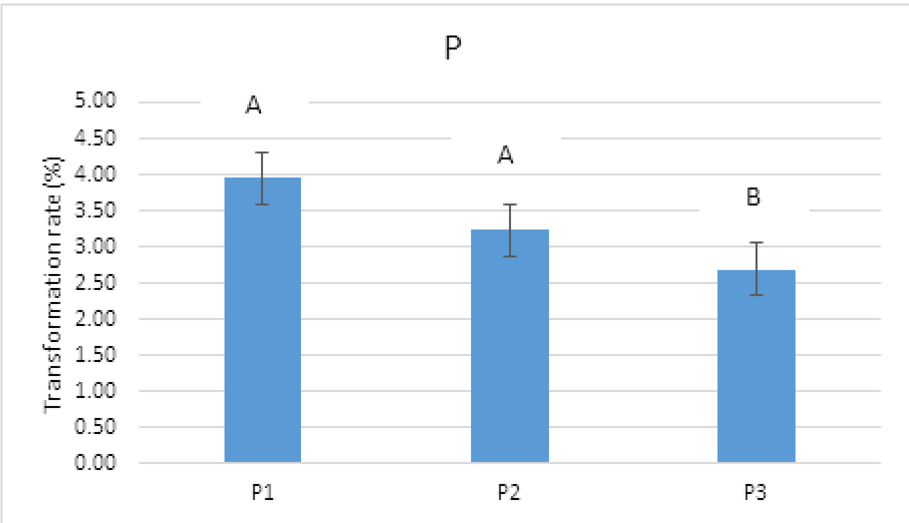

Fig. 2. Effect of P levels on NO_3^- transformation rate in lettuce (the average of mean values of the two studied seasons)

Note: P1 (15 mg L^{-1}), P2 (35 mg L^{-1}) and P3 (55 mg L^{-1}) in the form of H_3PO_4, added to the soil by fertigation system. Different letters mean significant at 5% level.

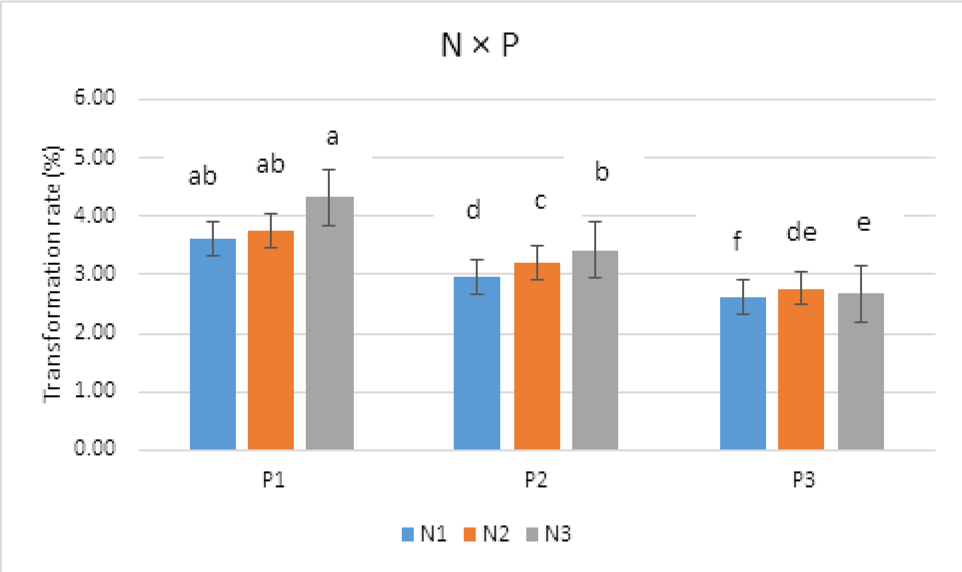

Fig. 3. Effect of N and P levels interaction on NO_3^- transformation rate in lettuce (the average of mean values of the two studied seasons)

Note: N1 (60 mg L^{-1}), N2 (120 mg L^{-1}) and N3 (180 mg L^{-1}) in the form of NH_4NO_3; and P1 (15 mg L^{-1}), P2 (35 mg L^{-1}) and P3 (55 mg L^{-1}) in the form of H_3PO_4, added to the soil by fertigation system. Different letters mean significant at 5% level.

Conclusion

Working on nutrient equilibrium, especially macro-nutrients inside the plant, is important for good and healthy production of crops. The main problem of N fertilization, especially for leafy crops, lies in the accumulation of nitrates within plant tissues, which causes severe damage to human health and environmental problems. The solution is to add this nutrient in balanced quantities without extravagance, considering its relationship with the rest of the other nutrients, especially P. The results of this study indicated that increase N supplies up to 180 mg L^{-1} led to increase the vegetative characters, yield and elemental content of lettuce plants. Regarding the P additions, increasing P supply up to 55 mg L^{-1} increased growth and productivity of plants during both studied seasons. Interaction effect between N and P levels indicated that 180 mg N L^{-1} combined with 55 mg P L^{-1} gave the highest lettuce productivity followed by 180 mg N L^{-1} combined with 35 mg P L^{-1}. While increase P level led to decrease NO_3^- concentration and accumulation rate of nitrate in plant tissues.

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محتوى الإتزان بين النيتروجين والفوسفور في نبات الخس (*Lactuca sativa* L.) المنزرع بتربة طينية

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تهدف هذه الدراسة إلى معرفة تأثير التسميد بتركيزات مختلفة من النيتروجين (٦٠ ، ١٢٠ ، ١٨٠ ملجم لتر$^{-1}$) مضاف في صورة نترات الأمونيوم (NH_4NO_3) من خلال نظام التسميد مع ماء الري fertigation، وكذلك تركيزات مختلفة من الفوسفور (١٥ ، ٣٥ ، ٥٥ ملجم لتر$^{-1}$) مضاف في صورة حامض الفوسفوريك (H_3PO_4)، سواء بصورة مفردة أو بالتداخل فيما بينهما، على صفات النمو ومحصول نباتات الخس (*Lactuca sativa L.*) وكذلك تراكم النترات في أنسجة النبات.نُفذت الدراسة تحت ظروف الحقل خلال موسمي النمو ٢٠١٩/٢٠٢٠ و ٢٠٢٠/٢٠٢١ بالمزرعة التجريبية بموقع الدقي بمحافظة الجيزة، مصر، في تصميم القطع المنشقة. تقع مستويات النيتروجين في القطع المنشقة الرئيسية، بينما تقع مستويات الفوسفور في القطع الفرعية، مع ثلاث مكررات. أشارت النتائج المتحصل عليها إلى أن زيادة مستوى النيتروجين المضاف حتى ١٨٠ ملجم لتر$^{-1}$ أدت إلى زيادة ملحوظة في الصفات الخضرية (ارتفاع النبات ، قطر الساق ، عدد الأوراق لكل نبات ومحتوى الكلوروفيل) لنبات الخس. بينما تم الحصول على أقل نمو وإنتاجية للنبات من خلال إضافة ٦٠ ملجم نيتروجين لتر$^{-1}$. فيما يتعلق بإضافات الفوسفور خلال موسمي النمو، زيادة مستوى الفوسفور المضاف حتى ٥٥ ملجم لتر$^{-1}$ أدى إلى زيادة النمو والإنتاجية للنباتات خلال موسمي الدراسة. أظهر تأثير التفاعل بين مستويات النيتروجين والفوسفور أن المعاملة ١٨٠ ملجم نيتروجين لتر$^{-1}$ مع ٥٥ ملجم لتر$^{-1}$ من الفوسفور أعطت أعلى إنتاجية للخس، تليها المعاملة ١٨٠ ملجم نيتروجين لتر$^{-1}$ مع ٣٥ ملجم لتر$^{-1}$ من الفوسفور. أخذ وزن محصول الخس نفس اتجاه النمو الخضري. أظهرت التحليلات الكيميائية أن زيادة جرعة النيتروجين أدت إلى زيادة نسبة النيتروجين، البوتاسيوم، الكالسيوم والماغنسيوم وكذلك النترات في أنسجة النبات. أدت زيادة مستوى الفوسفور إلى زيادة محتوى الفوسفور داخل النبات. أخيرًا، أدت زيادة مستوى الفوسفور إلى انخفاض تركيز النيتروجين في صورة النترات ومعدل تراكم النترات في أنسجة النبات.