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EFFECT OF NITROGEN FERTILIZATION ON EFFICIENCY AND REMOBILIZATION IN QUINOA CULTIVARS

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Abstract - This factorial split plot experiment was conducted to investigate the effects of the application of time and level of nitrogen on yield, grain content, remobilization efficiency, and nitrogen consumption of quinoa cultivars. The present work has a randomized complete block design with three replications in 2018 and 2019 in Khuzestan, Iran. The experimental factors herein included four levels of nitrogen fertilizer (no fertilizer application, 100, 200, and 300 kg/ha) and different administrations: (1) 50% at base stage + 50% at six-leaf stage, (2) 50% at base stage + 25% at six-leaf stage + 25% at mid-flowering stage, (3) 25% at base stage + 50% at six-leaf stage + 25% at mid-flowering stage, and (4) 25% base stage + 25% six-leaf stage + 50% mid-flowering stage. Furthermore, quinoa cultivars Gizat, Q26, and Titicaca were selected as the sub-plots. Comparing the two-year averages, we found that with the increase in the nitrogen fertilizer, grain yield, biological yield, remobilization (R), current photosynthesis (CP), remobilization contribution (RC), remobilization efficiency (RE), nitrogen content, and grain protein increased. Meanwhile, the level and current photosynthesis contribution (CPC), agronomic and physiological efficiency of nitrogen (NAE and NUE), and grain oil content decreased. The highest biological yield (11683 kg/ha) and grain yield (5675 kg/ha) were obtained applying 200 kg/ha of nitrogen divided into 25% at base stage + 25% at six-leaf stage + 50% at mid-flowering stage for cultivar Q26. The highest RE and NUE belonged to 100 kg/ha of nitrogen, 25% of which was at base stage + 50% at six-leaf stage + 25% at mid-flowering stage for cultivar Q26. Overall, the applying 200 kg/ha of nitrogen, 25% at base + 25% at six-leaf stage + 50% at flowering stage, and use of cultivar Q26 could be recommended based on our findings.

Keywords: nitrogen fractionation; grain protein; crop yield; current photosynthesis; remobilization efficiency.

Introduction

Quinoa (*Chenopodium quinoa* Willd), belonging to Chenopodiaceae, has recently been recognized as a strategic plant in the world. About 250 species of this family have been identified worldwide, which are found to be exotic plants in South Africa (Maradini Filho et al., 2015; Navruz-Varli & Sanlier, 2016). Quinoa seeds have high levels of lysine, methionine, and cysteine and contain about 15% to 20% protein (Matiasevich et al., 2006). Its high nutritional value and, most importantly, its resistance to weather and soil conditions, has doubled its value (Navruz-Varli & Sanlier, 2016). Quinoa is highly tolerant to abiotic stresses such as cold, salinity, and drought, which has increased its spread in different parts of the world. It could be a suitable alternative food in areas where rice cultivation is limited (Repo-Carrasco-Valencia et al., 2010).

Increasing agricultural production, along with the increase in population and development programs, has increased the use of chemical fertilizers, nitrogen in particular. Nitrogen

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is believed to be one of the most important nutrients. It contributes to the growth and biomass production of algae and plants and makes up about 3% to 5% of the total dry weight (Saroussi et al., 2017). Nitrogen is the most important nutrient required in the production of quinoa and its consumption management is of particular importance for success in grain production. Understanding nitrogen uptake and metabolism is necessary to maximize the efficiency of its application (Juergens et al., 2015). Low nitrogen efficiency is usually due to its loss through nitrification, leaching, nitrate removal from the plant, and ammonium sublimation (Zhu, 2000). Reducing the efficiency of nitrogen consumption not only leads to increased production costs but also has long-term detrimental effects on the environment and human health. To increase nitrogen efficiency, one should consider certain factors, including: (1) determination of the exact amount of fertilizer required for the crop; (2) timely use of the fertilizer; (3) a correct fractionation according to plant growth stages and the type of fertilizer (Bascuñán-Godoy et al., 2018; Grant & Entz, 2006). Nitrogen is the most important fertilizer affecting the grain yield and protein content of quinoa (Geren, 2015).

Quinoa needs different levels of nitrogen at different stages of growth; therefore, it is important for this product to consume an adequate amount of nitrogen at the right time (Kansomjet et al., 2017). A study showed that the effects of different levels of nitrogen on quinoa grain yield were significant, and the highest yield was recorded for the treatment of 240 kg/ha (Wang et al., 2020). Basra et al. (2014) stated that 75 kg/ha was an optimal level of soil nitrogen for the growth and development of quinoa to harvest the maximum economic yield in the ecological conditions of Egypt. Nitrogen application increased the grain yield, protein, and nitrogen content of quinoa compared to the control plants (Gomaa, 2013), and the role of genetic differences in quinoa cultivars in nitrogen use efficiency (NUE) was already reported (Kaul et al., 2005). Studies have reported that nitrogen consumption, to some extent, increases grain yield, whereas its excessive use causes non-essential accumulation of nitrogen in the plant shoots and increases its accumulation in the area of the soil far from the roots (Xu et al., 2020). Regarding sunflower, it has been reported that with nitrogen application, the amount and share of dry matter remobilization decrease, and the current photosynthesis increases (Gholinezhad & Sajedi, 2012; Dordas et al., 2008). In a study on its remobilization to the grains in wheat genotypes in response to nitrogen levels, it was found that with the increase in nitrogen fertilizer, remobilization increased, whose highest rate (71% more than that of the control) was observed in the treatment of 60 kg/ha of nitrogen (Alavi fazel, 2015).

Numerous studies have sought to improve NUE by developing nitrogen management methods based on better coordination between nitrogen supply and plant demand (Du et al., 2019). Nitrogen fractionation at the planting stage and during crop growth could be effective in shortening the presence of inorganic nitrogen in the soil solution before the harvest (Du et al., 2019). Nitrogen fractionation leads to higher use of nitrogen by the grain and thus a higher yield compared to once it is applied all at once (Kumar et al., 2018). Nitrogen fractionation is the most prevalent method of seed production worldwide. Splitting nitrogen at planting and 30 days after sowing also helps to improve the root yield (Du et al., 2019).

Considering the importance of nitrogen supply, this study was conducted to investigate the effects of the level and timing of nitrogen fertilizer application on yield, grain quality, NUE, and material remobilization of quinoa cultivars.

Materials and Methods

Treatment and experiment condition

This experiment was carried out in the 2018 and 2019 crop years in Ahvaz, Khuzestan (31° 20’N and 48°40’E; 18 meters above sea level). In this area the annual mean rainfall is 166 mm, making it an arid or semi-arid region. Table 1 represents the meteorological parameters and Table 2 depicts the physical and chemical properties of the farm soil.

The experiment was performed as a factorial split plot in a randomized complete block design with three replications. The primary factor included four levels of nitrogen (0 [control], 100, 200, and 300 kg/ha of urea source), and the secondary factor included four fertilizer fractionation regimes: (1) 50% at the beginning + 50% at six-leaf stage, (2) 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage, (3) 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage, and (4) 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage. There were also three quinoa cultivars (Gizat, Q26, and Titicaca). The measured traits included grain yield, biological yield, grain nitrogen content, grain protein content, grain oil content, remobilization (R), current photosynthesis (CP), remobilization contribution (RC), current photosynthesis contribution (CPC), remobilization efficiency (RE), nitrogen agronomic efficiency (NAE), and nitrogen physiological efficiency (NUE). Irrigation was carried out in early September with the aim of stimulating the weed germination and providing adequate moisture for plowing operations. Plowing was carried out with a reversible plow to a depth of 30 cm. To completely crush the lumps, the soil was disked twice, perpendicular to each other. In this experiment, each plot had six ridges with a

Table 1. Meteorological parameters in two years of 2018 and 2019.

Month	Temperature (°C)		Rainfall (mm)		Evaporation (mm)	
	2018	2019	2018	2019	2018	2019
Oct	28.3	29.2	37.8	62.5	194.9	169.2
Nov	19.4	18.9	37.8	37.0	74.7	83.1
Dec	15.3	14.4	20.5	119.2	44.7	46.0
Jan	14.2	13.4	45.1	31.0	49.5	63.2
Feb	15.5	15.7	13.8	21.2	71.9	85.4

Table 2. Soil physical and chemical properties of the test site in 2018 and 2019.

Years	Depth (cm)	salinity (ds/m)	PH	C (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)	clay (%)	silt (%)	sand (%)	soil texture
2018	0-30	5.4	9.7	0.58	0.058	10.5	245	22	30	48	lomy
2019	30-60	4.4	8	0.53	0.053	11.2	265	24	30	46	lomy

length of 500 cm, a width of 300 cm, and a distance of 50 cm from each other. According to the soil test, phosphorus fertilizer from triple superphosphate and potassium sulfate source was added to the soil at a rate of 100 kg/ha at the beginning. Nitrogen (from urea) was added to the soil through irrigation, considering the treatments. For each square meter, 40 seeds were mixed with sand at a ratio of 1:3. They were planted on 6th October at a depth of 2-3 cm. Plants were thinned from thefour-leaf to the six-leaf stage. Weed control was carried out by hand at the early stages when the plants were growing slowly. Harvesting took place at physiological maturity, at the point which the dried and hardened seeds could be easily separated by hand, and the plants began to dry and turn yellow. Harvesting was carried out manually on 14th January (Titicaca cultivar) and 23rd January (Q26 and Giza cultivars). To determine the grain yield at the ripening stage, 0.5 m of the beginning and 0.5 m of the end of lines three, four, and five were skipped, and harvesting was then carried out at an area equal to one m^2. Grain yield was calculated in kg/ha with a moisture content of 12%. At the physiological maturity, 10 plants from each plot were randomly selected and employed for the measurement of yield components. To determine the biological yield, an area of one m^2 was taken from each plot. The samples were transferred to the laboratory and placed in a ventilated oven at 75 °C for 48 hours to dry. Subsequently, their dry weight was measured. Additionally, two replicates of 500 seeds were counted and weighed in order to measure the 1000-seed weight.

Nitrogen, protein, and oil content

At the physiological maturity stage, after the sampling (0.5 g of milled grain), grain nitrogen was measured employing the Kjeldahl method. To measure the protein, after determining the percentage of nitrogen using the Kjeldahl method, the percentage of protein was calculated according to the following equation (Voltas et al., 1997):

$$\text{Protein} = N \times 5.7 \qquad \text{Eq. 1}$$

To determine the percentage of seed oil, a Soxhlet apparatus was utilized for three hours at 50 °C and the solvent was ether. By weighing the oil obtained from five gram of the powdered quinoa seeds, the percentage of extracted oil was determined (Uquiche et al., 2008).

Nitrogen use efficiency

The following equations were used to calculate nitrogen agronomic efficiency (NAE) and nitrogen physiological efficiency (NUE) indices (Fageria & Baligar, 2003):

$$\text{NAE (kg/kg)} = \frac{GY2 - GY1}{N} \qquad \text{Eq. 2}$$

where NAE represents the nitrogen agronomic efficiency, GY_2 and GY_1 are the grain yield with and without fertilizer application, respectively, and N is the nitrogen content.

$$\text{NUE (kg/kg)} = \frac{DW2 - DW1}{N2 - N1} \qquad \text{Eq. 3}$$

where NUE represents the nitrogen physiological efficiency and DW_2 and DW_1 are the total dry matter with and without fertilizer application (kg), respectively. In this equation N_2 and N_1 respectively represents the amount of nutrient absorption in the field where fertilizer is used and nutrient uptake rate in the control plot.

Remobilization efficiency

To calculate the rate of the remobilization of photosynthetic material to the seeds, the main panicles along with other aerial organs were harvested at the pollination stage. The dry weight of the vegetative organs was deducted at the pollination stage. The remobilization rate and the related parameters were utilized using the following equations (VanSanford & Mackown, 1987):

$$R = DW_1 - DW_2 \quad \text{Eq. 4}$$

$$CR = \frac{R}{GY} \times 100 \quad \text{Eq. 5}$$

$$RE = \frac{CR}{DW1} \quad \text{Eq. 6}$$

$$CP = GY - R \quad \text{Eq. 7}$$

$$CPC = 100 - RC \quad \text{Eq. 8}$$

where R is remobilization, DW_1 and DW_2 are the dry weight of vegetative organs at the beginning of pollination and at maturity (no grain), GY is the grain yield and CP and CPC represent respectively the current photosynthesis and current photosynthesis contribution. RC is the remobilization contribution and Re is the remobilization efficiency.

Statistical analysis

Before performing the combined analysis of the results of the two-year experiment, in which all the measurements had three replicates, the Bartlett test was used to ensure the uniformity of the experimental variance of the error. Since the difference between the error variances was not significant, combined analysis of variance was performed with MSTATC statistical software, and LSD tests at 0.05 probability level were used to compare the means.

Results and Discussion

Yield components

Our results revealed that grain yield components such as the number of panicles per plant, number of grains per panicle, and 1000-grain weight were affected by year, nitrogen content, and cultivar. The effect of nitrogen fractionation was only significant on the number of grains per panicle. The interaction between nitrogen and fractionation affected the number of panicles per plant and the number of grains per panicle. The effect of year on nitrogen also affected the number of grains per panicle and the 1000-grain weight. The four-way interaction of year × nitrogen × cultivar × fractionation significantly affected only the number of grains per panicle (Table 3). The grain yield components were higher in the first year than that in the second year. Q26 cultivar and fractionation F_1 yielded the highest number of panicles per plant and grains per panicle, but the highest 1000-grain weight belonged to Gizal and F_1. The application of 200 kg/ha of nitrogen also led to the highest values for yield components (Table 3).

The analysis of the four-way interaction also implied that, in the first year, the highest number of grains per panicle in Giza1 and Q26 cultivars was obtained from 200 kg/ha of nitrogen and fractionation F_4 and in Titicaca cultivar from 200 kg/ha of nitrogen and F_1. In the second year, the results were the opposite and the highest number of grains per panicle in Giza1 and Q26 cultivars were recorded for 100 kg/ha of nitrogen and fractionation F_2, yet in Titicaca cultivar 200 kg/ha of nitrogen produced the optimal results (Table 4). Numerous studies have reported improved quinoa yield components owing to nitrogen fertilization (Gomaa, 2013; Kansomjet et al., 2017). Hirzel et al. (2011) reported an increase in the number of panicles in quinoa following an increased application of nitrogen fertilizer. They identified the number of panicles as one of the most important factors determining grain yield. Basra et al. (2014) stated that different quinoa genotypes and nitrogen fertilizer levels yielded significantly affected the number of panicles. The highest number of panicles observed in CPJ2 and A9 genotypes was obtained from the application of 75 kg/ha of nitrogen. Danying et al. (2019) reported that the number of grains per panicle and the number of panicles per unit area were affected by different amounts of nitrogen fertilizer and fertilizer fractionation. Moradi Talebbeigi et al. (2018) demonstrated that the application of nitrogen and nitrogen fractionation (25% at the planting stage and 75% at the stem elongation stage) improved yields and oil of Safflower**.** Increased nitrogen fertilization increases the production of photosynthetic material, extends the flowering period, and improves the fertility of flowers. Thus, it increases the 1000-grain weight and the number of grains per plant, since it decreases the physiological removal of flowers and increases the green area of the plant and the number of sub-branches in the plant (Bascunan -Godoy et al., 2018). The results of the current study also indicated that in the first year, when rainfall and evapotranspiration in the growing season were lower, the grain yield components were higher. Similar results were reported by Du et al. (2019). This was due to a reduced stomatal conductance because of the

Table 3. Grain and biological yield, yield components, protein, and oil content of grain in cultivars of quinoa influenced by nitrogen application and fractionation in 2018-2019.

Treatment	Levels	Number Panicle	Number Grain Panicle	Weight 1000 Grain (g)	N (%)	Protein (%)	Oil (%)	Biological Yield (kg/ha)	Grain Yield (kg/ha)
Years	2018	13.8±0.20	3612±98.1	3.26±0.02	2.23±0.15	14.07±0.16	9.05±0.22	9293±121.6	4537±113.7
	2019	12.4±0.19	3446±67.6	2.86±0.03	1.93±0.10	13.67±0.11	8.85±0.14	5913±97.3	2857±75.9
$LSD_{0.05}$	-	**5.2**	**1071**	**1.18**	**0.96**	**4.91**	**3.03**	**1500**	**1110**
Cultivar	Giza1	13.1±0.22	3850±92.9	3.02±0.04	2.14±0.04	12.25±0.22	7.73±0.10	7867±210.7	3890±149.9
	Q26	14.6±0.21	3950±100.1	3.20±0.05	2.03±0.03	6.86±0.19	6.86±0.08	8454±225.7	4261±169.0
	Titicaca	11.6±0.19	2786±50.9	2.96±0.04	2.06±0.02	7.73±0.15	3.26±0.12	6488±141.2	2941±88.5
$LSD_{0.05}$	-	**4.3**	**874**	**0.96**	**0.59**	**3.26**	**874**	**1225**	**906**
Nitrogen (kg/ha)	0	10.8±0.28	3381±139.2	2.49±0.07	1.70±0.022	11.38±0.14	9.24±0.70	6566±533.8	2425±166.9
	100	13.4±0.30	3622±140.9	3.02±0.05	2.28±0.021	15.08±0.11	9.15±0.26	7517±228.7	3846±182.9
	200	14.6±0.26	3781±101.1	3.37±0.03	2.35±0.016	15.87±0.10	8.65±0.28	8558±186.5	4583±139.5
	300	13.6±0.16	3330±79.2	3.37±0.04	1.98±0.024	13.13±0.15	8.75±0.30	7772±214.9	3935±134.5
$LSD_{0.05}$		**3.7**	**757**	**0.84**	**0.68**	**4.59**	**2.14**	1061	**785**
Fractionation	F_1	12.8±0.38	3283±116.3	3.11±0.05	2.06±0.019	13.61±0.12	8.91±0.31	7550±226.8	3643±158.3
	F_2	13.4±0.29	3564±137.2	3.03±0.05	2.18±0.017	14.48±0.10	8.70±0.32	7741±271.5	3659±179.1
	F_3	13.3±0.26	3592±116.1	3.09±0.06	2.01±0.042	13.75±0.25	9.03±0.30	7627±258.8	3785±186.9
	F_4	12.9±0.23	3676±137.1	3.01±0.03	2.06±0.040	13.63±0.26	9.14±0.26	7493±252.6	3702±206.2
$LSD_{0.05}$	-	**2.8**	**757**	**0.63**	**0.51**	**3.47**	**2.14**	**803**	**594**
F value	Years (Y)	**	**	**	**	**ns**	**ns**	**	**
	Cultivar (C)	**	**	**	**ns**	**ns**	**	**	**
	Nitrogen (N)	**	**	**	**	**	*	*	**
	Fractionation (F)	**ns**	**	**ns**	**ns**	**ns**	**ns**	**	**ns**
	Y×C	**ns**	**	**ns**	**ns**	**ns**	**ns**	**	**
	Y×N	**ns**	**	*	**ns**	**ns**	**ns**	**	**ns**
	Y×F	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**	**
	C×N	**ns**	**	**ns**	**ns**	**ns**	**	**	**
	C×F	**ns**	*	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
	N×F	*	**	**ns**	**ns**	*	**ns**	**	**
	Y×C×N	**ns**	**	**ns**	**ns**	**ns**	**ns**	**	**ns**
	Y×C×F	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**	**ns**
	Y*N×F	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**	**
	N×C×F	**ns**	**	**ns**	**ns**	**ns**	**ns**	**	**ns**
	Y×C×N×F	**ns**	*	**ns**	**ns**	**ns**	**ns**	**	**ns**
Coefficient of variation (%)		**15.3**	**11.6**	**14.8**	**17.7**	**17.9**	**17.0**	**8.9**	**11.5**

ns, * and ** are non-significant, significant at 5% , 1%.
F_1: 50% at the beginning + 50% at six-leaf stage; F_2: 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage; F_3: 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage; and F_4: 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage.

Table 4. Biological yield (BY), Number of grains (NGP) and NUE in quinoa influenced by year ×cultivar×nitrogen× fractionation.

Nitrogen (kg/ha)	Fractionation	Cultivar	NGP		BY(kg/ha)		NUE (g/kg)	
			2018	2019	2018	2019	2018	2019
		Giza1	3298±48.80	3791±91.20	9110±58.80	4388±30.30	-	-
0	-	Q26	3666±27.60	3884±38.30	9459±30.60	4607±19.60	-	-
		Titicaca	2193±51.90	3456±96.40	7466±22.90	4369±15.70	-	-
100	F_1	Giza1	3272±255.1	2130±169.1	9117±118.8	5249±81.60	39.1±2.59	33.1±1.21
		Q26	2579±150.2	2980±58.51	9196±86.20	6109±98.90	44.2±0.67	33.5±1.20
		Titicaca	1706±210.8	2552±174.2	7180±130.6	4883±148.3	29.7±1.73	26.4±0.56
	F_2	Giza1	4535±177.3	4490±133.2	10735±167.0	5876±201.2	60.6±0.99	39.3±1.43
		Q26	5073±55.30	4888±169.2	11688±53.10	6279±131.7	65.0±2.34	40.0±2.20
		Titicaca	3145±228.9	2748±132.7	7309±182.40	4704±172.6	38.0±1.75	33.3±0.98
	F_3	Giza1	5114±56.10	3980±165.4	10630±112.2	6035±129.6	57.3±0.62	47.3±0.62
		Q26	4314±242.3	3864±158.3	10860±196.6	6037±84.80	60.8±2.15	44.1±1.40
		Titicaca	2281±136.6	2585±151.3	6216±206.50	4641±150.6	31.0±1.85	24.4±1.88
	F_4	Giza1	4563±96.50	4582±116.1	10908±76.90	5691±106.9	60.8±0.84	43.1±0.66
		Q26	4941±154.5	4635±126.2	11534±311.5	6537±105.8	66.2±2.09	46.2±2.09
		Titicaca	3153±54.50	2823±104.1	7929±99.90	5055±114.7	43.3±0.41	33.3±0.41
200	F_1	Giza1	4093±47.90	3442±81.20	10285±101.4	6531±37.50	28.1±0.33	25.8±0.87
		Q26	4709±63.50	3492±80.10	11381±77.80	7276±88.70	32.6±0.90	34.0±0.14
		Titicaca	3268±120.7	2602±39.70	8247±20.80	6373±81.40	22.2±0.14	32.2±2.09
	F_2	Giza1	4194±183.7	3449±79.60	9706±133.1	7252±78.70	27.3±0.44	34.0±0.28
		Q26	4817±199.5	3566±34.40	11312±152.3	7629±149.5	32.5±1.64	34.1±2.00
		Titicaca	3113±92.90	2587±52.30	8061±144.70	6979±121.3	20.3±0.55	25.3±0.54
	F_3	Giza1	4970±78.30	3335±128.1	10858±128.9	7425±101.8	29.1±0.41	26.8±1.24
		Q26	4944±138.8	3370±95.40	10980±97.60	8527±187.7	30.3±0.36	31.6±0.98
		Titicaca	3073±111.7	3501±106.9	8523±131.30	6053±183.9	18.6±0.60	18.0±2.12
	F_4	Giza1	5367±31.91	4126±99.20	11008±143.8	7125±113.7	30.4±0.62	29.3±0.33
		Q26	5355±90.90	3847±115.1	11684±200.2	8381±85.80	33.9±0.24	31.9±0.34
		Titicaca	2622±67.50	2909±54.80	7275±88.20	6508±90.70	17.6±0.34	27.6±0.29
300	F_1	Giza1	4327±143.1	3196±91.90	9731±179.1	7433±48.10	16.7±0.23	21.0±0.54
		Q26	4524±118.1	3764±63.50	10009±211.9	9400±159.3	18.9±0.34	23.6±0.78
		Titicaca	3037±105.4	2821±121.6	7183±54.20	6225±69.80	12.1±0.41	13.5±0.63
	F_2	Giza1	3817±48.20	3386±73.80	10112±102.5	5585±111.7	17.0±0.13	17.3±0.84
		Q26	2668±114.5	3270±107.2	10037±91.10	7665±110.2	17.6±0.17	18.3±0.41
		Titicaca	2756±19.30	2745±21.80	7670±52.00	7789±103.0	12.7±0.20	16.2±0.68
	F_3	Giza1	3777±37.30	3414±35.60	9170±180.1	5496±97.10	17.0±0.17	16.6±0.57
		Q26	3807±32.50	3857±18.30	10451±210.3	5535±99.10	19.1±0.18	15.8±0.38
		Titicaca	2967±182.1	2768±36.80	8364±90.48	4641±137.2	13.4±0.30	12.1±0.26
	F_4	Giza1	3900±56.40	3385±104.1	10096±127.7	5699±115.4	16.8±0.07	13.5±1.06
		Q26	3669±102.8	3257±46.30	9575±35.50	6181±170.1	17.3±0.21	16.0±0.26
		Titicaca	2292±34.60	2514±99.40	6929±121.6	5543±91.60	10.4±0.15	10.8±0.98
$LSD_{0.05}$			**117**		**216**		**0.57**	

F_1: 50% at the beginning + 50% at six-leaf stage; F_2: 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage; F_3: 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage; and F_4: 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage.

high transpiration of plants. The higher rainfall in the second year triggered more nitrogen leakage, which reduced the availability of nitrogen to the plants. Moreover, rainfall at the pollination and grain formation stage can disrupt pollination and hence grain formation. Thus, fractionation of nitrogen could increase nitrogen uptake by reducing leaching and runoff, particularly in years with heavy rainfall (Vos, 2009; Kelling et al., 2015). According to our findings, fractionation of nitrogen at the beginning and as F_4 can supply a sufficient amount of fertilizer to maximize crop production without increasing the risk of fertilizer loss in the environment. It is consistent with the results of nitrogen fertilizer application in the literature (Du et al., 2019; Lin et al., 2014).

Grain content

Levels of nitrogen, protein, and oil in the grains were affected by the level of nitrogen fertilization, cultivar, and nitrogen fractionation. Nitrogen fertilization × fractionation only affected protein content and cultivar × nitrogen fertilization only affected oil content (Table 3). The results showed that the levels of nitrogen, protein, and oil in the grain produced in the first year were higher than those in the second year. Furthermore, among the studied cultivars, the highest grain nitrogen and protein belonged to Gizal, whereas the highest level of oil was recorded for the Q26 cultivar.

Nitrogen consumption also improved the amount of nitrogen and hence protein in the grains produced and reduced their oil content. The highest level of nitrogen (2.35%) and protein (15.9%) belonged to the plants fertilized with 200 kg/ha of nitrogen. The highest level of oil (9.2%) was recorded for the control treatment. The fractionation of nitrogen fertilizer improved grain oil and protein content: the greater the share of the reproductive stages was, the more the accumulation of osmolytes changes was observed in favor of oil. The highest level of nitrogen and protein were obtained from F_2, while the highest oil content was recorded for F_4 (Table 3).

The interaction of nitrogen and fractionation also exhibited that the nitrogen fractionation strengthened the effect of nitrogen on the oil and the protein content of the grains. The highest protein content of the grains was harvested from the plants fertilized with 200 kg/ha of nitrogen fractionated as in F_3, being 43% higher than that of the control. It was also found that low levels of nitrogen had negative effects on oil content, and the highest oil content was obtained from those treated with 300 kg/ha of nitrogen fractionated as in F_4, being 5% higher than that of the control (Table 5).

Table 5. Grain and biological yield, yield components, and protein and oil contents of grains in cultivars of quinoa influenced by nitrogen application × fractionation.

Nitrogen (kg/ha)	Fractionation	Number of Panicle	Number of Grains Per Panicle	Protein (%)	Oil (%)	Biological Yield (kg/ha)	Grain Yield (kg/ha)
0	-	10.8±0.28	3381±139.1	11.38±0.14	9.15±0.72	6566±553.8	2425±166.9
100	F_1	12.4±0.85	2537±171.5	14.41±0.24	8.40±0.39	6956±350.4	3173±217.7
	F_2	12.8±0.48	4147±275.2	15.75±0.09	8.40±0.64	7765±447.5	4138±222.3
	F_3	13.7±0.45	3690±265.7	15.25±0.30	8.90±0.53	7403±478.8	3848±366.9
	F_4	14.6±0.49	4116±236.7	14.90±0.13	8.89±0.51	7942±417.4	4225±398.3
200	F_1	14.8±0.62	3601±162.1	14.75±0.24	8.17±0.50	8349±348.4	4522±288.3
	F_2	15.3±0.53	3621±179.4	16.27±0.06	8.43±0.46	8490±407.9	4488±277.1
	F_3	15.2±0.42	3865±193.4	16.36±0.11	9.00±0.47	8728±313.4	4586±259.7
	F_4	13.3±0.35	4038±259.4	16.11±0.11	9.38±0.72	8664±248.6	4736±308.8
300	F_1	13.3±0.27	3612±161.3	13.90±0.05	8.72±0.71	8330±302.4	4453±190.0
	F_2	14.5±0.28	3107±190.8	14.50±0.15	8.96±0.57	8143±206.5	4088±198.1
	F_3	13.5±0.38	3432±111.6	12.36±0.12	9.52±0.55	7276±146.3	3779±318.7
	F_4	12.9±0.27	3170±141.8	11.76±0.18	9.41±0.53	7337±321.7	3421±302.7
$LSD_{0.05}$	-	**1.4**	**379**	**1.74**	**1.07**	**530**	**392**

F_1: 50% at the beginning + 50% at six-leaf stage; F_2: 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage; F_3: 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage; and F_4: 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage.

Numerous studies have reported certain changes in grain content following nitrogen fertilization. Abou-Amer & Kamel (2011) stated that with the increase in the use of nitrogen fertilizer, the level of nitrogen in the quinoa grains increased. Leesawatwong & Rerkasem (2003) stated that the use of nitrogen at the right time and rate increases the nitrogen and protein content of the grains. With the increase in the level of nitrogen fertilizer, the grain protein content increases. Nitrogen application near the flowering stage increases post-flowering nitrogen uptake, grain protein, and grain protein concentration (Leesawatwong & Rerkasem, 2003). Zhao et al. (2012) showed that a greater proportion of nitrogen was allocated to the developing grains once supplementary nitrogen was provided during the late growth stage until the flag-leaf stage and this increased nitrogen in oat kernels. Präger et al. (2018), stated that Titicaca cultivar had the highest level of grain oil, which is consistent with the results of this experiment. Whenever nitrogen is absorbed by the plant, it is converted into amino acids and then proteins inside the plant, playing different roles in plant physiology. It seems that with an increase in soil nitrogen, further nitrogen is absorbed by the plant. Prolonged nitrogen fertigation increased the nitrogen content of the leaves, which delays leaf senescence. Accordingly it play an important role in maintaining canopy assimilation to sustain yield accumulation during the whole growing season (Zhou et al., 2018). Nitrogen is utilized for improving vegetative growth and grain formation, and its excess amount accumulates in the form of protein in the grains (Roy & Singh, 2006). The results herein revealed that the protein content in quinoa grains increased with an increase in nitrogen application up to 200 kg/ha and then decreased, which may be due to the fact that quinoa does not have the genetic potential to absorb more nitrogen. The percentage of nitrogen in different plant tissues is directly associated with the availability of nitrogen in the soil, morphology, how the root system develops, soil moisture, irrigation management, the amount of nutrients in the soil, and time and method of fertilizer application. Therefore, if a sufficient amount of nitrogen is provided to the roots through fertilization, the plant could absorb it. Thus, the percentage of nitrogen in plant tissues would increase. Employing nitrogen, the potential production of hydrocarbons reduces, and a greater proportion of photosynthetic material is allocated to protein formation. This significantly reduces the level of oil in quinoa grains. Furthermore, as the amount of nitrogen increases, the nitrogenous protein background increases, the substances available for fatty acid synthesis decrease, and the percentage of grain oil decreases.

Yields

Our findings indicated that quinoa yields were affected by the two-way and three-way interactions of the factors studied. The effect of year × nitrogen fertilization × cultivar was significant only on the biological yield (Table 3). In addition, the grain yield and the biological yield in the first year were higher than those in the second year, and Q26 had a higher biological yield compared to Giza1 or Titicaca. It was also found that the application of 200 kg/ha of nitrogen led to the highest grain yield (88%) and biological yield (30%), compared to the control (Table 3). Among the different nitrogen fractionation regimes, F_2 brought the best nitrogen efficiency in biological yield production (7741 kg/ha), yet the highest grain production (3785 kg/ha) was obtained from F_3 (Table 3).

Moreover, the highest biological yield and grain yield were obtained from 200 kg/ha. In the fractionation regime where the share of early growth stages was higher, the biological yield had a better improvement, while in those where the share of the reproductive phase was higher, the grain yield improved. The highest grain yield (4736 kg/ha) was obtained from the plants that received 200 kg/ha of nitrogen fractionated as in F_4, whereas the highest biological yield (8728 kg/ha) was obtained from the F_3 (Table 5). The effect of nitrogen fertilization × fractionation × year on grain yield also showed that the effects of nitrogen and fractionation differed from year to year. In the first year, when the amounts of rainfall, evaporation, and transpiration were lower, the highest grain yield was obtained from 100 kg/ha fractionated as in F_4. Meanwhile, in the second year 300 kg/ha of nitrogen led to better results in the early stages (Table 6).

The four-way interactions also showed that, in both years, the highest yield belonged to Q26. In the first and second year, 100 and 300 kg/ha of nitrogen had the best results respectively. In the first year, the fractionation of fertilizer as in F_4 led to the best results, while in the second year, F_1 yielded the best results (Table 7). Researchers have reported a positive response of grain yield to the application of nitrogen fertilizer in different plants (Basra et al., 2014; Abebe & Feyisa, 2017). The optimal nitrogen level for quinoa was reported to be 120 kg/ha (Mosseddaq et al., 2016). In another study, Awadalla and Morsy (2017) reported that quinoa reacted strongly to nitrogen fertilizer application, and the highest biological yield was obtained from 150 kg/ha. Regolana cultivar had the highest yield. The fractionation of nitrogen fertilizer into four equal parts at the pre-planting, tillering, stem formation and flowering stages increased the biological yield (Awan et al., 201). Shi (2012) suggested that dividing nitrogen fertilization into basal and topdressing applications can increase grain yields and the efficiency of nitrogen recovery. Geren (2015) also

Table 6. Grain and biological yield, yield components, and protein and oil contents of grains in cultivars of quinoa influenced by year × nitrogen × fractionation.

Nitrogen (kg/ha)	Fractionation	Grain Yield (kg/ha)		CP (kg/ha)	
		2018	2019	2018	2019
0	-	3013±169.3	1836±56.8	413.6±20.1	104.9±7.3
100	F_1	3878±234.6	2469±149.3	376.6±23.1	138.8±13.0
	F_2	5565±159.4	2711±195.0	545.4±42.7	137.9±13.1
	F_3	4970±177.3	2726±172.1	497.0±47.7	157.9±11.0
	F_4	5676±151.6	2774±157.7	567.6±35.1	138.7±11.4
200	F_1	5539±103.9	3504±69.3	552.8±30.4	224.8±5.3
	F_2	5342±166.1	3633±98.8	534.2±36.6	233.4±8.5
	F_3	5203±273.5	3969±228.4	520.3±37.3	258.4±14.6
	F_4	5464±302.3	4008±164.4	546.4±49.5	264.1±10.8
300	F_1	4775±230.8	4130±190.7	477.5±30.2	238.8±6.8
	F_2	4732±249.5	3444±98.7	473.2±23.0	176.1±21.8
	F_3	4951±134.2	2606±154.7	495.1±24.9	142.0±13.5
	F_4	4448±130.1	2393±116.4	444.8±33.4	104.7±14.6
$LSD_{0.05}$		**277**		**27.4**	

F_1: 50% at the beginning + 50% at six-leaf stage; F_2: 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage; F_3: 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage; and F_4: 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage. CP; Current photosynthesis.

reported that with the increase in the level of fertilizer, the yield of quinoa increased. The optimal level of nitrogen to produce the highest grain yield was found to be 150 kg/ha. With the increase in nitrogen application, single plant weight and biological yield increase, which is owing to the increased plant green area and thus increased distribution of photosynthetic material between the vegetative and reproductive organs (Zangani, 2006). According to our results, in the first year, when the rate of evapotranspiration was higher, photosynthesis, and hence yields, decreased, which could have been due to a limited stomatal conductance and reduced gas exchange in the plants (Table 3). Nitrogen application improved the yield components and ultimately increased the grain yield by increasing the plant fertility and prolonging the flowering period (Bascuñán-Godoy et al., 2018). Liu et al. (2019) found that delaying the topdressing fertilization of wheat farms boosted crop productivity. The nutrients released in the F_4 treatment met the requirements of the crops, promoting the transport of dry matter from the vegetative organs to grains and panicles during yield formation, thereby increasing the yield. Our results implied that with nitrogen fractionation, once the plant is exposed to a sufficient amount of nitrogen at the reproductive stage, it produces higher grain yield components and thus a higher grain yield. Moreover, in rainy years, due to the fact that nitrogen becomes unavailable to the plants, the yields decrease.

Nitrogen application efficiency

Year, cultivar, nitrogen content, nitrogen fractionation, and their two-way interactions significantly influenced the nitrogen agronomic efficiency (NAE) and nitrogen physiological efficiency (NUE) (Table 7). Their three-way and four-way interactions were significant only on the NUE (Table 7). The NAE and NUE of nitrogen application were higher in the first year than in the second year. Q26, Gizal cultivar and Titicaca respectively held the first, second, and third places. Additionally, the application of 200 kg/ha of nitrogen, and its fractionation as in F_2 yielded the optimal results in terms of NAE and NUE (Table 7).

Table 7. Nitrogen use efficiency and remobilization in cultivars of quinoa influenced by nitrogen application and fractionation in 2018 and 2019.

Treatment	Levels	NAE (g/kg)	NUE (g/kg)	R (kg/ha)	CP (kg/ha)	RC (%)	CPC (%)	RE (%)
Years	2018	24.1±0.48	30.8±1.60	149.9±5.4	480.3±10.4	39.1±1.11	61.0±1.42	23.5±0.9
	2019	22.7±0.45	27.5±0.98	319.6±8.7	164.7±6.1	34.1±1.04	66.1±1.54	19.5±1.9
$LSD_{0.05}$	-	**2.9**	**3.9**	**53.1**	**109.8**	**15.3**	**18.0**	**6.8**
Cultivar	Giza1	23.7±0.53	31.1±1.60	236.5±13.4	335.6±22.2	34.3±1.57	65.8±1.23	21.9±0.83
	Q26	24.7±0.52	33.6±1.71	259.2±14.9	373.1±23.4	35.1±1.99	65.2±2.99	20.3±0.91
	Titicaca	21.8±0.62	22.6±1.12	208.6±11.9	258.9±13.1	40.5±1.79	59.7±1.09	22.2±0.96
$LSD_{0.05}$	-	**2.9**	**4.3**	**43.3**	**89.6**	**12.5**	**14.7**	**5.5**
Nitrogen (kg/ha)	0	-	-	151.4±12.8	259.2±18.4	30.1±1.2	70.1±3.2	20.3±1.6
	100	21.0±0.54	43.3±1.40	252.0±8.4	320.0±23.8	37.3±1.9	62.8±1.9	24.8±3.1
	200	28.2±0.34	28.1±0.64	290.5±7.3	391.8±19.9	42.3±1.0	58.3±1.8	20.4±1.0
	300	21.1±0.35	16.0±0.37	245.1±12.2	319.0±20.2	36.8±1.8	63.1±1.8	20.4±1.1
$LSD_{0.05}$	**-**	**2.9**	**4.3**	**37.5**	**77.6**	**10.8**	**12.7**	**4.8**
Fractionation	F_1	21.8±0.79	27.0±1.17	250.7±12.8	316.0±28.4	39.7±3.2	60.8±2.2	22.9±4.1
	F_2	24.6±0.60	30.5±1.98	238.8±16.1	327.3±21.7	36.5±2.2	63.6±1.6	21.6±1.01
	F_3	23.8±0.42	28.5±1.32	234.3±16.2	323.7±25.4	36.3±1.6	63.7±2.7	22.7±1.5
	F_4	23.4±0.75	30.5±2.20	215.4±15.7	323.1±24.1	34.0±2.7	66.1±2.0	18.6±0.9
$LSD_{0.05}$	**-**	**2.2**	**3.7**	**37.5**	**5.7**	**10.8**	**12.7**	**4.8**
F value	Years (Y)	**	**	**	**	**	**	**
	Cultivar (C)	**	**	**	**	**	**	**
	Nitrogen (N)	**	**	**	**	**	**	**
	Fractionation (F)	**	**	**	**ns**	**	**	**
	Y×C	**	**	**	**	**	**	**
	Y×N	**	**	**	**	**	**	**
	Y×F	**	**	**	**	**	**	**
	C×N	**	**	**	**ns**	**	*	**
	C×F	**	**	**	**ns**	**	**	**
	N×F	**	**	**	**	**	**	**
	Y×C×N	**ns**	**	**	**	**	**	**
	Y×C×F	**ns**	*	**	**ns**	**	**ns**	**
	Y*N×F	**ns**	**	**	**	**	**	**
	N×C×F	**	**	**	**ns**	**	**	**
	Y×C×N×F	**ns**	**	**	**ns**	**	**	**
Coefficient of variation (%)		**5.8**	**6.9**	**8.6**	**13.0**	**16.0**	**10.8**	**12.1**

ns, * and ** are non-significant, significant at 5% , 1%.
NAE; Nitrogen Agronomic Efficiency, NUE; Nitrogen physiological efficiency, R; Remobilization, CP; Current photosynthesis, RC; Remobilization Contribution, CPC; Current photosynthesis Contributio, RE; Remobilization efficiency.

The analysis of the effect of year × cultivar × nitrogen fertilizer × nitrogen fractionation on the NUE showed that in the first year of the study, the highest NUE of nitrogen was obtained applying 100 kg/ha fractionated as in F_4, regardless of the cultivar. It was 60.8, 66.2, and 43.3 g/kg in Giza1, Q26 and Titicaca cultivars, respectively. In the second year, the highest yields of Giza1 and Q26 cultivars were obtained from the fractionation of nitrogen as in F_3, meanwhile, the highest yield of Titicaca cultivar was obtained from the fractionation of nitrogen as in F_4 (Table 8).

According to the law of diminishing returns, the highest NUE is usually obtained by absorbing the first unit of fertilizer and decreases with an increase in nitrogen application (Biswas & Mukhherejee, 1987). Even though it seems that at low nitrogen levels the level of nitrogen available to the plant decreases in view of leaching or nitrogen sublimation, the losses due to leaching and sublimation are higher at high nitrogen levels, ineffective use of nitrogen and reduced nitrogen uptake and efficiency. In this study, in the second year, higher rainfall and evapotranspiration resulted in lower nitrogen application efficiency compared to that in the first year (Table 7). The examination of different levels of nitrogen revealed that the highest efficiency belonged to the control treatment (Abou-Amer & Kamel, 2011). The differences in genotypes might be assigned to the genetic differences in nutrient uptake. Therefore, the superiority of Q26 cultivar could be attributed to its higher ability to use environmental conditions as well as its high grain yield compared to the other cultivars. On the other hand, the immature root system at the early growth stage limits basal absorption of nitrogen fertilizer (Lin et al., 2014). However, once fertilizer is applied at flowering, the roots of the plants perfectly develop, and most of the nitrogen is absorbed within a few days following the application of the fertilizer. Hence the conflict between the supply of and demand for nitrogen would be resolved. Therefore, fractionation of nitrogen application markedly improved the nitrogen uptake of the plants during the middle and late growth stages, and the final nitrogen uptake and nitrogen harvest index increased. Furthermore, fractionation of nitrogen enhanced sink capacity, which resulted in higher grain weight and number of grains (Du et al., 2019; Xiangbei et al., 2019).

Remobilization

The results in the present work illustrated that year, nitrogen application, nitrogen fractionation, and cultivar significantly affected remobilization (R), current photosynthesis (CP), remobilization contribution (RC), current photosynthesis contribution (CPC), and remobilization efficiency (RE). Their two-way, three-way, and four-way interactions also significantly affected the parameters, except for CP (Table 7).

Based on our findings, in the first year, the RC and RE were higher than those in the second year. However, in the second year, the R and the CPC were higher. Among the cultivars studied, the highest values of R and CP were recorded for Q26, yet the highest values of RC and RE belonged to Titicaca (Table 7). The highest values of R, CP, and CPC were obtained utilizing 200 kg/ha of nitrogen. The highest CPC was obtained from control treatment, and the highest RE was related to the use of 100 kg/ha of nitrogen. Among the different fractionation regimes, the highest values of R and RC were recorded for F_1, whereas the highest CPC was recorded for F_4. The highest RE was recorded for F_3 (Table 7). The analysis of year × nitrogen × fractionation on CPC showed that in both years of the study, the highest CP was recorded for the use of 200 kg/ha of nitrogen. In the second year, F_1 yielded the optimal results (552 kg/ha), but in the second year, F_4 gave the optimal results (264 kg/ha) (Table 6).

The four-way interaction also showed that the highest R in the first year of the study was recorded for Q26 and the application of 100 kg/ha and F_3. In the second year, the highest value was obtained from the same cultivar, but with 300 kg/ha and F_1. The highest RC in the first and second year was obtained from Q26 with the application of 100 and 300 kg/ha of nitrogen. In the first year, fractionation regimes with a higher share for the beginning had better results. However, in the second year, the fractionation regime with a higher share for the flowering stage was ideal. A higher share of CP in all three cultivars was recorded for the application of 200 kg/ha of nitrogen fractionated as in F_4 in the first year, but in the second year, it was recorded for the control treatment. Overall, the highest RE in both years (40% and 26.3%) were recorded for Giza1 and the application of 100 kg/ha of nitrogen and fractionation as in F_2 (Table 8).

With optimal use of nitrogen, leaf growth is completed earlier, and excess photosynthetic material is stored and transferred to the grain following pollination (Kazemi Poshtmasari et al., 2008). Reduction or zero application of nitrogen causes an imbalance of nutrients in the plants, shortening the plant size, yellowing its leaves, reducing vegetative growth and canopy development, finally reducing the amount of CP and its efficiency. All these factors affect the quantity and quality of the product (Tousi kehal et al., 2011). This effect could be explained through the fact that a rational basal-top-dressing nitrogen ratio improves the accumulation of nitrogen in the leaves, which is significantly and positively correlated with chlorophyll activity and enhances photosynthetic capacity (Li et al., 2013). Hitz et al. (2017) assumed that a rational basal-top-dressing nitrogen ratio would significantly improve the activities of enzymes in various light energy conversion processes and maintain a high level of activity after anthesis, which might be a primary reason why the photosynthetic capacity observed under this combined treatment was significantly higher than

Table 8. Remobilization in quinoa influenced by year ×cultivar×nitrogen× fractionation

Nitrogen (kg/ha)	Fractionation	Cultivar	R (kg/ha)		RC (%)		CPC (%)		RE (%)	
			2018	2019	2018	2019	2018	2019	2018	2019
		Giza1	107.9±0.58	210.1±4.70	38.3±2.1	18.8±1.5	62.0±1.9	81.2±1.4	27.7±1.86	16.8±0.86
0	-	Q26	100.9±0.85	218.2±8.40	33.6±5.6	23.9±2.0	66.7±3.6	76.1±5.6	13.8±0.99	17.8±1.34
		Titicaca	92.3±2.900	179.1±6.70	52.1±2.6	13.8±0.6	48.3±1.2	86.2±4.6	30.0±1.70	15.7±0.86
100	F_1	Giza1	210.0±17.0	250.9±3.30	52.3±6.4	29.6±6.0	47.7±2.9	70.4±3.4	20.2±4.47	19.5±1.63
		Q26	282.1±20.8	308.5±25.3	64.3±5.6	21.2±4.0	36.0±4.7	78.8±3.5	27.9±1.35	22.6±1.23
		Titicaca	195.5±11.2	254.0±13.8	61.9±4.6	22.1±4.5	38.3±3.5	77.9±2.5	24.2±6.44	22.1±3.85
	F_2	Giza1	295.3±7.80	331.6±19.3	49.2±1.5	28.5±7.9	51.0±3.7	71.5±2.9	40.0±1.47	26.3±1.22
		Q26	196.3±8.70	334.4±24.7	28.9±1.2	38.2±1.0	71.3±2.9	61.8±3.4	22.8±1.67	22.1±1.14
		Titicaca	172.5±14.5	240.5±4.20	45.9±3.7	26.3±4.8	54.3±2.3	73.7±0.5	29.4±1.48	20.4±1.59
	F_3	Giza1	241.9±17.2	309.6±16.4	42.7±3.4	20.1±1.2	57.7±5.7	79.9±2.7	35.1±1.46	24.5±7.95
		Q26	301.7±15.5	342.9±5.30	51.6±6.9	28.2±1.3	48.7±0.9	71.8±4.3	35.2±0.88	23.9±1.62
		Titicaca	200.9±10.0	254.9±6.80	73.5±9.6	41.7±1.3	27.0±8.3	58.6±6.0	36.3±2.52	24.0±0.56
	F_4	Giza1	133.7±8.11	293.7±4.20	30.7±3.9	32.9±1.0	69.3±3.4	67.1±8.8	22.6±4.77	23.3±1.15
		Q26	176.4±18.7	355.6±8.20	26.8±4.6	23.3±4.6	73.3±3.5	76.7±4.7	22.4±2.50	22.4±2.31
		Titicaca	105.1±1.92	260.0±20.1	35.1±3.6	21.1±0.2	65.0±3.7	78.9±9.6	12.3±3.74	14.6±1.56
200	F_1	Giza1	112.7±4.21	388.3±3.80	23.7±4.1	33.6±1.4	76.3±3.6	66.4±2.9	16.6±1.49	23.0±0.77
		Q26	212.5±10.1	395.5±1.50	33.1±1.5	38.2±6.7	67.3±2.8	70.8±4.9	22.1±0.65	26.1±1.27
		Titicaca	166.0±9.60	383.1±9.90	37.8±2.3	52.9±1.9	62.3±0.8	47.1±1.3	28.5±3.05	25.2±118
	F_2	Giza1	124.9±4.70	420.4±4.20	22.7±1.2	56.1±4.0	77.7±4.0	43.9±2.3	17.3±1.33	16.3±1.11
		Q26	175.6±11.0	440.4±3.20	29.8±0.8	45.9±0.7	70.3±1.9	54.1±1.4	20.5±1.83	19.8±1.49
		Titicaca	134.3±4.30	384.5±13.6	33.4±1.2	53.3±2.8	67.0±2.7	46.7±4.1	22.5±0.71	20.5±1.05
	F_3	Giza1	144.1±3.40	435.5±15.6	25.5±4.9	39.5±3.6	74.7±1.4	60.5±3.6	18.4±3.65	15.8±1.36
		Q26	161.2±8.60	538.1±16.9	33.0±2.9	65.9±3.7	67.3±0.2	34.1±6.3	19.8±0.50	18.1±1.16
		Titicaca	115.5±2.40	391.9±10.4	31.1±9.6	69.2±3.3	69.0±4.5	30.8±3.3	19.7±4.80	15.7±0.97
	F_4	Giza1	121.5±3.10	460.1±16.1	25.0±4.7	62.0±3.4	75.3±1.4	38.0±2.4	16.6±1.11	15.9±100
		Q26	238.9±17.5	503.5±4.90	51.3±8.8	52.1±8.3	49.3±4.5	47.9±3.5	31.7±4.64	23.3±164
		Titicaca	112.3±4.80	412.3±7.61	39.9±6.0	59.4±0.7	60.7±4.8	40.6±9.6	20.4±3.97	16.7±1.68
300	F_1	Giza1	214.5±5.70	472.0±7.40	54.9±4.3	54.0±5.8	45.3±1.8	46.0±6.9	32.6±2.62	25.9±0.98
		Q26	150.5±5.90	533.9±8.11	33.0±2.9	60.5±2.3	67.3±1.3	39.5±3.4	20.8±1.99	20.1±1.50
		Titicaca	180.8±6.31	396.9±5.10	50.2±0.5	49.1±2.9	50.3±1.1	50.9±3.7	31.8±1.14	19.5±1.51
	F_2	Giza1	141.5±4.90	370.9±8.41	30.6±3.4	48.9±3.7	69.7±4.8	51.1±1.2	21.0±1.46	20.3±0.90
		Q26	146.1±3.90	421.5±14.4	30.6±3.5	52.8±3.5	69.7±1.0	47.2±1.5	17.8±186	22.2±1.12
		Titicaca	106.3±3.90	385.7±4.10	30.9±2.9	43.2±4.7	69.3±7.9	56.8±4.6	19.9±1.93	17.9±0.91
	F_3	Giza1	138.3±12.7	290.7±3.21	29.2±2.5	24.4±4.3	71.0±4.5	75.8±5.6	23.9±2.11	21.2±0.48
		Q26	116.4±3.20	327.1±5.80	20.3±8.2	17.0±2.9	74.3±4.0	83.0±6.4	14.6±9.32	14.8±0.72
		Titicaca	170.4±3.90	233.3±3.60	48.5±3.5	28.2±1.2	51.7±6.0	71.8±2.6	39.8±1.92	22.2±0.73
	F_4	Giza1	102.5±11.6	291.8±10.2	28.3±4.0	24.3±3.6	72.0±0.6	75.7±6.2	10.5±1.36	17.5±0.89
		Q26	104.0±3.60	256.1±4.90	28.6±4.6	17.5±1.9	71.7±2.0	82.5±2.0	13.5±1.56	18.2±0.91
		Titicaca	89.5±6.10	242.7±4.60	47.5±5.6	31.0±1.2	53.0±1.5	69.0±1.6	11.2±1.14	12.6±0.47
$LSD_{0.05}$			**10.8**		**2.21**		**3.3**		**0.74**	

F_1: 50% at the beginning + 50% at six-leaf stage; F_2: 50% at the beginning + 25% at six-leaf stage + 25% at mid-flowering stage; F_3: 25% at the beginning + 50% at six-leaf stage + 25% at mid-flowering stage; and F_4: 25% at the beginning + 25% at six-leaf stage + 50% at mid-flowering stage.

that obtained with the other treatments. It has been reported that with the increase in the amount of nitrogen, the level of remobilization from vegetative parts to grains increases as well, which augments the grain filling speed and grain weight. This could be attributed to the faster absorption of materials from vegetative parts and thus their transfer to grains. The results of fertilizer fractionation also showed that the use of nitrogen in the final stage of the plant growth and development improved the yield components, specifically the number of grains per panicle and the weight of the grains. This is indicative of improved remobilization owing to nitrogen application. Moreover, the rate of photosynthesis is related to the available nitrogen transfer rate, and with the increase in nitrogen application, the rate of photosynthesis per unit area increases; as a result, the RC decreases (Barraclough et al., 2010). Nitrogen increases CP by producing a higher leaf area and continuing it by decelerating leaf aging. Nitrogen also creates stronger reservoirs to receive nutrients from CP by increasing the number of fertile tillers, increasing the number of spikes, and increasing the number of fertile florets. In other words, when there are no strong reservoirs in the plant, photosynthesis will not increase (Yang et al., 2001).

Conclusion

Our results shed light on the fact that nitrogen application with a proper fractionation improved quinoa production. Grain yield components, grain and biomass yields, oil and grain protein content, and nitrogen use efficiency and remobilization in this plant were significantly affected by nitrogen administration. In the years in which the growing season of this plant faces high rainfall, due to nitrogen leaching and disruption of flowering, the efficiency of nitrogen application and production in this plant decreases. In this case, it is better to divide nitrogen application from the beginning of growth. We also found that Q26 was of a higher nitrogen yield and efficiency compared to the other two cultivars. Additionally, the application of 200 kg/ha and fractionated as in F_4 (25% base stage + 25% six-leaf stage + 50% mid-flowering stage) is in favor of grain production; yet in rainy years, the application of 300 kg/ha and fractionated under early growth stages (F_1 and F_2) are also necessary.

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