Effect of Sources and Application Times of Nitrogen Fertilizer on Wheat Yield and Nitrate Leaching in Different Soil Textures

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Research Article

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Abstract

Aims Nitrogen fertilizers have destructive impacts on the environment through nitrate leaching.

Methods To evaluate the effects of sources and application times of nitrogen fertilizer on wheat yield and nitrate leaching in different soil textures, an experiment was conducted using the factorial arrangement of randomized complete block design (RCBD). The treatments were two sources of nitrogen fertilizer including ammonium nitrate (AN) and urea (NN), applied three different times during the year with a control treatment: total application before sowing (T_1), total application in spring (T_2) and application of half the amount before sowing and half the amount in spring (T_3) in different soil textures (sandy loam, silty clay loam and silty clay) with three replications during three growing seasons 2015-16 (Y_1), 2016-17 (Y_2) and 2017-18 (Y_3).

Results The results indicate that the effects of different soil textures in increasing grain yield differed significantly. The soil texture of silty clay loam compared to other soil textures (sandy loam and silty clay) differed in grain yield. Interaction effects of N sources and application times were significant at the 1 percent level for the three different soil textures. The results also showed that in the soil textures of sandy loam and silty clay at T_3, compared to silty clay loam, grain yield increased. Silty clay loam with T_2 increased grain yield compared to other soil textures, with a yield of 6863.6 kg ha^{-1}. The effect of nitrogen fertilizer at different application times was significant in increasing the protein content in the silty clay and sandy loam. The protein percentage in the silty clay was 10.76 at T_2 and was 10.93 at T_2 in the sandy loam. In addition, AN compared to NN had a greater effect on the percentage of grain protein.

Conclusion Nitrogen fertilizer application times affect grain yield and protein content in different locations. Moreover, AN increases protein content compared to NN. Maximum soil nitrate concentration was obtained at 80-100 cm depth in both fertilizer treatments and in sandy loam soil, and nitrate concentration increased during the experiment.

Introduction

Wheat (*Triticum aestivum* L.) is the most important crop in the world and can grow in various environments. In fact, wheat has the highest and widest adaptation to different climate conditions among cereals (Sheibani and Ghadiri, 2012). The increasing need for cereals in Iran, especially wheat, due to irregular population growth and the goal of achieving self-sufficiency, makes this crop even more important.

In general, the human needs for food security and environmental protection are in conflict with the use of chemical fertilizers (Xu et al. 2020). However, during the last half century, the yield of crops has increased significantly because of the use of chemical fertilizers, especially N fertilizers (Peng et al. 2011). Chemical fertilizers containing N are commonly used to balance the economic performance of wheat because this crop has trouble absorbing N (Woodley et al. 2018; Linton et al. 2020). Accordingly, the efficiency of consumption of this fertilizer has been reported to be very low (Garnett et al. 2009). Low N efficiency not only increases production costs, but also affects crop lodging, vulnerability to pest infestation, hard pan formation and soil agglomeration, and even drastically reduces economic performance (Ishfaq et al. 2020). On a large scale, the lack of access to N added to soil creates many environmental problems, such as nitrate leaching, ammonium sublimation, runoff and erosion, loss of soil biodiversity and global N_2O emissions (Galloway et al. 2013; Coskun et al. 2017). Along with the problem of water scarcity, the world's agriculture is also facing the challenge of nitrate leaching (Li et al. 2016; Wang et al. 2017; Xu et al. 2020). Optimizing the use of N fertilizers, in addition to creating economic stability in cropping systems and the stabilization of crop production, will reduce harm to the environment (Tabak et al. 2020).

The performance of crops is affected by climatic factors such as temperature and solar radiation, which will be absorbed by the crop during growing season (van Ittersum et al. 2013). In addition to climatic factors and soil texture, time management of N fertilizer application is effective in increasing crop yield. Wang et al. (2017) concluded that the application of 185 kg ha^{-1} of N is effective in increasing wheat yield. Despite the genetic improvement of N use efficiency (Mueller et al. 2019), several studies show that split application of N fertilizers improves the uptake and use efficiency of N in crops by synchronizing crop fertilizer demand (Rehman et al. 2013; Huang et al. 2018; Ishfaq et al. 2020). Delin (2005) confirmed that AN fertilizer is the highest source of N available to the crop compared to the consumption of ammonium sulfate (AS) and NN fertilizers. According to his results, the rate of N uptake by the crop from AN was 64 to 74.8 percent, for NN was 61.5 to 64.5 percent and for AS was 61.7 to 63.4 percent. Wang et al. (2015), by conducting an experiment on the interaction of the three fertilizers NN, AN and AS, with soil N on wheat, showed that the application of N fertilizer had a significant effect on soil N and crop dry matter compared to the control treatment.

Traditionally, farmers in Iran used high rates of N to increase crop yield resulting in evidence of increasing nitrate leaching under various land-use systems. Along with weed resistance, this has elevated the need to find better methods. The objectives of this research were to investigate the effects of sources and application times of N fertilizer on wheat yield and nitrate leaching in three locations with different soil textures Kermanshah (Bistoon Plain) under the agroclimatic conditions of west Iran.

Material And Methods

Project locations

This project was carried out on three farms in the plains of Kermanshah, on the Bistoon Plain. The Bistoon Plain is one of the most highly productive wheat centers in west Iran. Table 1 illustrates the attributes of the three experimental farms. Before the experiment, combined samples of soil at a depth of 0-30 cm were prepared and sent to the laboratory for determination of nitrogen, phosphorus and potassium content as well as other parameters (Fig. 1). Figure 1 presents the geographical situation and soil characteristics of the selected farms.

Table 1. The climate and soil attributes of experimental areas

Climate								
Year	Elevation	T_{mean}	T_{max}	T_{min}	Humidity	Precipitation	ET_{ref}	
2015-16	1322	16.33	24.76	7.90	40.89	363.55	1597.45	
2016-17		16.40	24.84	7.96	40.70	360.28	1600.88	
2017-18		16.47	24.92	8.02	40.52	357.01	1604.31	
Soil								
Soil texture	pH	EC (ds cm^{-3})	Soil Bulk Density (g cm^{-3})	O.C (%)	O.M(%)	N (%)	P (mg kg^{-1})	K (mg kg^{-1})
Sandy loam (Ilkhaniabad)	7.4	1.54	1.56	1.02	1.76	0.09	13.1	235
Silty clay loam (Sarmaj)	7.32	1.51	1.51	1.21	2.08	0.1	14.2	281
Silty clay (Samangan)	7.12	1.52	1.51	1.53	2.63	0.12	15.2	301

Implementation of experiment

To evaluate the effects of sources and application times of nitrogen fertilizer on grain yield, dry matter, protein percentage of wheat and nitrate leaching, three experiments were conducted using the factorial arrangement of randomized complete block design (RCBD) with three replications during the growing seasons of 2015-2017.

The treatments were two sources of N fertilizer including ammonium nitrate (AN) and urea (NN); application times including total application before sowing (T_1); total application in spring (T_2) and half application before sowing and half in spring (T_3); in three locations with different soil textures (Ilkhaniabad: sandy loam, Sarmaj: silty clay loam and Samangan: silty clay).

N fertilizers were applied by spraying. Due to the results of lab tests on the soil, phosphate and potassium fertilizers were not needed in this study. N fertilizer application based on the soil tests was only 60 kg ha^{-1}. Treatment also depended on the type of fertilizer and time of application. Dimensions of plots were 2×3

m^2, 0.5 m between plots, 2 m between duplicates and 20 cm between planting lines. Seeding rate was 400 plants per m^2 based on 1000 seed weight of Mihan cultivar. During the growing season, in addition to crop care, notes such as date of emergence, tillering, stalking, clustering and harvesting were recorded.

Nitrate leaching evaluation

During the growing season and simultaneous with the crop harvest, samples from 80-100 cm soil depth were obtained from each field using augers to measure nitrate leaching. The nitrate concentration of soil extracts was determined using the Kjeldahl method. The Nitraver method was used to measure the nitrate N (NO_3-N) content in the soil extract, and the wavelength was determined using a spectrophotometer (model LibsaS12).

Evaluation of protein percentage

Grain protein was measured using the Bradford method (Bradford, 1976). For this purpose, the samples were first ground with a mill (Arthur H. Thomas, Philadelphia, PA) using a 1 mm sieve. The crude protein was determined with Kjeldahl apparatus (Kjeldahl Vap50 Gerhardt, Germany). After placing the samples into the device, the nitrogen in the sample was measured using Eq. 1:

$$T.N = \frac{[(T - B) \times N \times 0.014 \times 100]}{S} \qquad (1)$$

where T.N was the total nitrogen percentage; T was the volume of acid used for sample titer (ml); B was the volume of acid used for control volumetric measurement (ml); S was the crop sample weight (g); and N was the normality level of sulfuric acid (0.02 is normal). After measuring the total nitrogen of the sample, the protein percentage was calculated by applying a coefficient of 6.25 percent crude protein in different treatments.

Statistical analysis

The results were analyzed using SAS 9.4 (2013). The normality test was performed before the data analysis of variance. Duncan's multiple range tests at the 1 and 5 percent levels of probability were used to compare the means. In addition, independent polynomial comparisons were used to test the effect of linear or nonlinear effects of sources and application times of N fertilizer on wheat yield and nitrate leaching in different soil textures on quantity and quality characteristics of wheat measured at the 5 percent probability level.

Results

Analysis of variance

According to the results of variance analysis in sandy loam soil, the effect of year, source, application time and interactions of year × N source, N source × application time and year × N source× application time on wheat grain yield and nitrate leaching were significant at the one percent level. Other sources of variables were not significant. Also, all treatments were significant for dry matter and protein percentage at the 1 percent probability level.

Table 2. The mean square analysis of variance of grain yield, total dry matter, protein percentage and nitrate leaching in three soil textures

Texture	S.O.V.	Grain yield	Dry matter	Protein %	N leaching
Sandy loam	Year	16013581.4**	221562237.5**	8.28**	0.005**
	Year×Rep	62185.9	43891.1	4.56	0.00
	Application Time (AT)	964579**	1361045**	13.2**	0.006**
	Fertilizer Source (FS)	79043.6 n.s	492 n.s	16.7**	0.002**
	Year×TA	110140.3 n.s	436469.2**	1.6**	0.00**
	Year×FS	342727**	477564**	13.09**	0.00**
	TA×FS	398092.5**	433432.2**	6.4**	0.002**
	Year×TA×FS	498971.2**	466510.2**	0.71**	0.002**
	Error	42385.2	24300.1	0.23	0.00
	C.V (%)	9.12	14.4	4.9	0.41
Silty clay loam	Year	4683751.6**	6029696.22**	6.5**	0.005**
	Year×Rep	29678.6	24907.4	7.8	0.00
	Application Time (AT)	557473.9**	693657.4**	0.32 n.s	0.007**
	Fertilizer Source (FS)	250785.1**	275918.5**	7.63**	0.002**
	Year×TA	168810.6**	149574**	1.17**	0.00**
	Year×FS	188446.5**	481251.8**	0.07 n.s	0.00**
	TA×FS	642222.9**	763590.7**	0.18 n.s	0.002**
	Year×TA×FS	58298.1*	53240.7*	0.4**	0.002**
	Error	15732.7	14767.4	0.1	0.00
	C.V (%)	8.92	3.36	3.5	0.75
Silty clay	Year	2853762.1**	1401790.7**	22**	0.006**
	Year×Rep	23909.7	45327.7	12.2	0.00
	Application Time (AT)	277543.3**	241390.7**	2**	0.006**
	Fertilizer Source (FS)	2216.9 n.s	27112.9 n.s	25.2**	0.002**

	Year×TA	420654.7**	227112.9**	1.89**	0.00**
	Year×FS	110082.7*	273868.5**	0.01**	0.00**
	TA×FS	654012.7**	134501.8*	0.54**	0.002**
	Year×TA×FS	737541.5**	206590.7**	0.9**	0.002**
	Error	34957.3	32516.6	0.05	0.00
	C.V (%)	6.86	4.9	3.21	0.54

n.s: not significant; (*) and (**) represent significant difference over control at p<0.05 and p<0.01, respectively

Grain yield

Figure 2 shows the effect of source and application time of N fertilizer on wheat grain yields in the three soil textures. The maximum wheat grain yield was obtained by NN-T_3 and AN-T_3 in the sandy loam (6603.1 and 6476.3 kg ha^{-1}, respectively) (Fig. 2a). Different results were observed for the silty clay loam; the highest wheat grain yield was obtained in AN-T_2 (6995.3 kg ha^{-1}). It seems that the source of N fertilizer and the time of its application have a closer relationship with this soil texture (Fig. 2b). For silty clay, the highest wheat grain yield was acquired in NN-T_3 treatment in (7112.3 kg ha^{-1}). No significant difference was observed between any of the treatments at the source and application time of N fertilizer in the silty clay soil texture (Fig. 2c).

Dry matter

Figure 3 shows the effect of source and application time of N fertilizer on the dry matter of wheat in the studied soil textures. The maximum dry matter in the sandy loam was obtained by NN- T_3, AN-T_3 and AN-T_2 treatments (9698.7, 9604.4 and 9402.4 kg ha^{-1}, respectively). The treatment of NN-T_3 produced 56.78 percent more dry matter than the control treatment, which highlights the importance of N fertilizer application (Fig. 3a). In silty clay loam texture, AN-T_2 and AN-T_1 treatments resulted in the highest dry matter content in wheat (10143.1 and 9932 kg ha^{-1}). The treatment of AN-T_2 produced 31.63 percent more dry matter than the control treatment.

In silty clay, no significant difference was observed between application times and N fertilizer sources on dry matter content. However, the highest dry matter was obtained using the NN-T_3 treatment (10043.6 kg ha^{-1}), which produced 25.37 percent more dry matter. Among the soil textures studied in this experiment, silty clay produced the highest dry matter content among the control treatments (8011.1 kg ha^{-1}). This heavier soil texture produced no significant difference between the type of N fertilizer source and the time of application (Fig. 3c).

Protein percentage

The comparison of means for protein percentage in sandy loam showed statistical significance: AN of 10.44, T_3 application time with 10.93 and AN-T_3 treatment with an average of 11.01 percent (Fig. 4a). The comparison of means for protein percentage in silty clay loam were in the top groups: AN with 10.98 percent; T_1 and T_3 together with 10.65 percent; and AN-T_1 with 11.1 percent (Fig. 4b). Finally, the results of comparing the means for the protein percentage in silty clay showed AN with a protein content of 11.24 percent; T_2 and T_1 with a protein content of 10.76 and 10.27 percent, respectively. The AN-T_2 treatment with an average of 12.23 percent was the best result (Fig. 4c).

Nitrate leaching

The result of comparing the means in sandy loam showed that the highest nitrate leaching fraction was present under NN and T_1 treatments (0.37 mg l^{-1} was reported in both treatments). NN (0.38 mg l^{-1}) was also observed under T_1 and T_2 treatments (Fig. 5a). Results differed in silty clay loam, with heavier soil texture than sandy loam, so nitrate leaching was expected to be lower. Based on the results, the highest amount of nitrate leaching was reported in NN-T_1 and NN-T_2 (0.34 mg l^{-1}). The results also confirmed that there was no difference between T_1 and spring T_2 if NN fertilizer was used (0.35 mg l^{-1}), although the lowest nitrate leaching rate in both fertilizer sources was reported at T_3 (0.33 mg l^{-1}) (Fig. 5b). The results of nitrate leaching fraction in silty clay soil texture showed no significant difference between the two sources of fertilizer (0.34 mg l^{-1}). However, the application time can affect the nitrate leaching rate. The highest leaching rate was observed in fertilizer applied at T_1 (0.36 mg l^{-1}). This indicates an increase in nitrate leaching during the autumn and winter seasons. The lowest amount of nitrate leaching was reported in AN-T_3 (0.32 mg l^{-1}) (Fig. 5c).

Interaction effects

According to the results of analysis of variance, the effect of year on grain yield was significant. The first year of the experiment in sandy loam and silty clay loam had the highest grain yield and in silty clay the highest yield was obtained from the second year's crop. The interactions of year × N source × application time on grain yield confirmed that the highest grain yield in sandy loam was in the first year, using NN (7462.8 kg ha^{-1}) and T_3 and T_2 (7527.7 and 7252.4 kg ha^{-1}), respectively. In the first year of the experiment, the highest grain yield (7271.3 kg ha^{-1}) was acquired, and in the second and third years of the experiment, 22.7 and 14.97 percent of grain yield were decreased, respectively (Table 3).

As discussed in the previous paragraph, silty clay loam showed the highest grain yield in the first year of the experiment (7230.6 kg ha^{-1}), which differed from the grain yield in the second and third years of the experiment by decreasing 8.46 and 13.4 percent, respectively. In this soil texture, the highest grain yield was obtained using the AN application treatment (7357.8 kg ha^{-1}) and in T_2 and T_3, respectively (7413.3 and 7245.7 kg ha^{-1}). On the other hand, the grain yield results in silty clay were different from the other two soils due to its heavier texture. In this type of soil, no significant difference was observed between the two N sources and in the three years of the experiment, but the highest grain yield was obtained in the second year of the experiment (7104.6 kg ha^{-1}). The grain yield decreased by 10.86 percent in the third year of the experiment. Due to its heavy texture, no significant difference was observed between application times and especially between NN sources (Table 3).

Table 3. The interaction effects of year × N source × application time of fertilizer on grain yield and total dry matter (TDM) of wheat

Soil Texture	N Fertilizer Time	Grain yield (kg.ha^{-1})			TDM (kg.ha^{-1})		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Sandy loam	Control	2456.93 f	2283.18 g	2309.96 fg	6320.5 h	6052.8 i	6184.9 hi
	AN	7080.2 b	5600.9 d	6260.5 c	10344.8 b	7983.7 f	9491.8 c
	NN	7462.8 a	5604.6 d	6104.7 c	10673.9 a	7959.6 f	9196.6 d
	T1	7033.7 b	5590.2 e	5886.3 d	10180.5 b	8058.4 e	8837.5 e
	T2	7252.4 a	5539.8 e	6118.9 d	10553.3 a	7785.8 g	9315.9 d
	T3	7527.7 a	5768.3 e	6542.5 c	10793.7 a	8071.1 e	9838.3 c
	Average	7271.3 A	5620.7 C	6182.6 B	10509.2 A	7971.7 C	9336.1 B
Silty clay loam	Control	3417.64 f	3422.71 f	3407.87 f	7765.5 f	7702.8 f	7648.9 f
	AN	7357.8 a	6745.3 c	6211.6 e	10509.6 a	9560.6 c	9344.8 d
	NN	7103.9 b	6491.8 d	6311.6 de	10282.4 b	9140.8 e	9562.4 c
	T1	7032.1 b	6549.5 c	6296.4 cd	10282.5 b	9385.7 d	9545.7 c
	T2	7413.3 a	6970.5 b	6331.4 cd	10619.9 a	9627.5 c	9564.9 c
	T3	7245.7 a	6335.6 d	6157.7 d	10357.1 b	9037.2 e	9252.1 d
	Average	7230.6 A	6618.4 B	6261.7 C	10410.3 A	9350.4 B	9453.9 B
Silty clay	Control	3710.85 de	3998.3 d	3868 d	7925.1 g	8102.8 f	8005.4 fg
	AN	6926.8 ab	7181 a	6254 c	9964.1 ab	10070.4 ab	9535.9 d
	NN	6883.6 b	7028.4 ab	6410.9 c	10173.6 a	9831.9 bc	9700.8 c
	T1	6537.6 b	6985.5 a	6441.5 b	10111.1a	9890.4 b	9757.4 c

	T2	7156.4 a	7165.8 a	6031.7 c	9963.3 ab	10035.8 ab	9255.7 e
	T3	7022.1 a	7162.6 a	6524.2 b	10162.6 a	9925.7 ab	9840.5 bc
	Average	6905.3 B	7104.6 A	6332.4 C	10074.9 A	9950.8 A	9618.1 B
In each column, there is no significant difference between treatments with common letters according to Duncan test at <0.01.							

In the silty clay loam control field, the highest protein content was reported in the first year of the experiment (11.4%). The protein percentage in the silty clay control field was also different from the sandy loam control field due to its heavier soil texture. In these heavier soils, no significant difference was observed between the two control treatments in the three years of the experiment, but the highest protein percentage was obtained in the first year (12.1 and 12.2%, respectively). On the other hand, no significant difference was observed between application times and especially between NN sources. Continuous cultivation of wheat in all three soils led to a significant decrease in protein content. This highlights the importance of using legumes in crop rotation to avoid using so much chemical fertilizer (Table 3).

The mean values of nitrate leaching in control treatment were much lower than N application treatments. In the sandy loam control fields, application time had an effect on nitrate leaching: most occurred at T2 (42 mg l^{-1}). However, there was no significant difference over the three years. In silty clay loam, a decreasing trend of nitrate leaching was seen over the three years, especially with T3 application times, in which the decrease was significant. No significant difference was observed between the types of N fertilizer. In silty clay, the highest amount of nitrate leaching was seen in the second year of the experiment (0.384 mg l^{-1}). In this type of soil, the amount of nitrate leaching using AN was less than when using NN. The decreasing trend of nitrate leaching in T_3 was significant (Table 4).

Table 4. The interaction effects of year × N source × application time on protein percentage and nitrate leaching of wheat

Soil Texture	N Fertilizer	Protein percentage			N leaching (mg.l^{-1})		
	Time	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Sandy loam	Control	11.4 a	11.2 a	11.1 a	0.31 h	0.23 i	0.23 i
	AN	10.1 bc	10.2 b	9.81 c	0.37 f	0.36 g	0.37 f
	NN	9.3 d	10.01 c	9.89 c	0.38 e	0.37 f	0.38 e
	T1	10.1 bc	9.92 c	9.88 c	0.41 b	0.4 c	0.41 b
	T2	11.2 a	10.12 bc	10.02 c	0.4 c	0.42 a	0.38 e
	T3	11.2 a	10.23 b	10.12 bc	0.4 c	0.4 c	0.39 d
	Average	10.4 A	10.09 AB	9.94 B	0.39 A	0.39 A	0.386 A
Silty clay loam	Control	12.1 a	11.4 ab	11.3 ab	0.23 e	0.2 ef	0.23 e
	AN	11.11 b	10.81 bc	10.5 c	0.38 c	0.37 d	0.37 d
	NN	10.9 b	9.99 cd	10.06 cd	0.39 b	0.37 d	0.38 c
	T1	10.1 cd	10.1 cd	10.12 cd	0.4 a	0.4 a	0.39 b
	T2	12.01 a	10.82 bc	11.01 b	0.4 a	0.4 a	0.39 b
	T3	12.01 a	10.43 c	10.93 b	0.4 a	0.39 b	0.37 d
	Average	11.22 A	10.43 B	10.52 B	0.394 A	0.386 AB	0.38 B
Silty clay	Control	12.2 a	12.1 a	11.9 a	0.2 f	0.2 f	0.21 f
	AN	12.1 a	11.89 a	11.77 ab	0.36 e	0.37 d	0.36 e
	NN	11.2 b	11.85 a	11.07 b	0.38 c	0.38 c	0.39 b
	T1	9.91 c	9.21 d	10.1 c	0.37 d	0.39 b	0.39 b
	T2	11.1 b	10.81 bc	12.01 a	0.36 e	0.4 a	0.38 c
	T3	12.01 a	10.87 bc	11.96 a	0.37 d	0.38 c	0.37 d
	Average	11.26 AB	10.92 AB	11.38 A	0.368 B	0.384 A	0.378 AB
In each column, there is no significant difference between treatments with common letters according to Duncan test at <0.01.							

Correlation coefficients

The results of Pearson's correlation coefficients showed that the highest correlation was found between wheat grain yield and dry matter production (0.93^{**}). No significant correlation was observed between the percentage of grain protein and dry matter. On the other hand, the correlation between nitrate leaching values and grain yield, dry matter and protein percentage was inverse and negative. The highest negative correlation was reported between dry matter and nitrate leaching (-0.88). In other words, with increased nitrate leaching, there was decreased dry matter, grain yield and protein percentage in the wheat crops.

Table 5. Pearson's correlation coefficients among measured traits of wheat

Traits	GY	DM	PP	N-L
GY	1			
DM	0.93^{**}	1		
PP	$0.24^{n.s}$	$0.34^{n.s}$	1	
N-L	-0.55^{*}	-0.88^{**}	-0.51^{*}	1

$^{n.s}$: not significant; (*) and (**) represent significant difference over control at $p<0.05$ and $p<0.01$, respectively.

Abbreviations: Grain yield (GY), dry matter (DM), protein percentage (PP) and nitrogen leaching (N-L)

Relationship between grain yield and nitrate leaching

The values of grain yield (kg ha^{-1}) and nitrate leaching (mg l^{-1}) using different forms of N, application times and soil textures are shown in Fig. 6. Results mentioned in the previous sections did not show the effect of nitrate accumulation in the soil on wheat grain yield with different sources of N. To quantitatively demonstrate such relationships, linear regression was used. The relationship between the values of increasing wheat grain yield and nitrate leaching using different sources of N was compared with the control treatment using scatter diagrams. The mean nitrate leaching in the control treatments and in different textures of sandy loam, silty clay loam and silty clay were 0.257, 0.222 and 0.023 mg l^{-1}, respectively. Wheat grain yield values of 2350, 3416 and 3825 kg ha^{-1} were obtained. These results comparing sandy loam with silty clay loam and silty clay showed that reducing nitrate leaching by 0.035 and 0.054 mg l^{-1}, wheat grain yield increased by 1066 and 1475 kg ha^{-1} in the control treatment, respectively. This means that the role of soil texture in reducing nitrate leaching is significant, with heavier soil texture increasing wheat grain yield (Fig. 6).

The results of AN application on wheat showed that the average leaching of nitrate using T_1 application times in sandy loam, silty clay loam and silty clay soils were 0.355, 0.347 and 0.284 mg l^{-1}, respectively, which compared to the control treatment led to wheat grain yields of 3136, 3132 and 2941 kg ha^{-1}. Using T_2, nitrate leaching values in AN treatments were 0.3, 0.321 and 0.283 mg l^{-1}, respectively. This reduction in nitrate leaching increased wheat grain yields to 3698, 3285 and 2576 kg ha^{-1} compared to the control treatment. Using T_3, nitrate leaching values in the three soil textures were 0.295, 0.32 and 0.305 mg l^{-1}, respectively, which increased grain yield to 3654, 2625 and 2648 kg ha^{-1} compared to the control treatment of wheat grain. The important point about the application of AN fertilizer is the reduction of leaching in silty clay soil, which led to a reduction in the grain yield distance of wheat compared to the control treatment. It seems that in heavier soil textures, total application of AN fertilizer in T_1 had a much greater effect on increasing wheat grain yield (silty clay loam and silty clay). On the other hand, the best time for the AN application in silty clay soil was T_2. Comparing the treatments of different soil textures, results showed that the heavier the soil texture, the better the growth conditions for wheat. The grain yield increased and nitrate leaching decreased significantly (Fig. 6).

Nitrate leaching values using NN treatment at T_1 in sandy loam, silty clay loam and silty clay were reported as 0.396, 0.367 and 0.275 mg l^{-1}, respectively, which showed an increase of 0.088, 0.139 and 0.077 mg l^{-1} compared to the control treatment. Wheat grain yield at T_1 in sandy loam, silty clay loam and silty clay increased to 3629, 2577 and 2467 kg ha^{-1}, respectively. These results for T_2 were 0.106, 0.166 and 0.078 mg l^{-1}, respectively, leading to grain yields of 3439, 3033 and 2696 kg ha^{-1}. Applying nitrate fertilizer at T_3 increased leaching values by 0.7, 0.166 and 0.1 mg l^{-1}, respectively, compared to the control treatment. This increase in nitrate leaching led to increased grain yields of 3993, 3131 and 2976 kg ha^{-1}, respectively (Fig. 6).

Discussion

According to the results, control treatments for all three soil textures showed the lowest values of grain yield; this issue demonstrates the vital role of N fertilizers in increasing wheat grain yield. The result also points to the excessive use of chemical fertilizers in previous years: All three soils studied in this experiment showed a severe dependence on N fertilizer. If chemical fertilizers are not used after the dependence is established, the crop yield will be significantly reduced. Golba et al. (2013), by examining different management methods such as low and high N fertilizer and its division into two stages, observed that management methods affect wheat grain yield. Also, the amount of N absorbed in the crop indicates the state of N during the crop growth period. Increasing the efficiency of N utilization increases nitrogen uptake by crops, dry matter production and grain yield (Soltani et al. 2006).

The relationship between minerals such as N in the soil and water-soluble sugars is influenced by environmental factors. When wheat has easier access to N and is able to absorb more of it, protein content increases and sugars decrease. With the intensification of photosynthetic activities, the amount of sugars increase, and protein deficiency occurs. This becomes more pronounced with organic N fertilizers due to the gradual release of elements (Ma et al. 2006). On the other hand, nitrate leaching during the growth period is a function of the initial soil N, the type of N used, crop growth conditions, crop N uptake and fertilizer and irrigation management (Li et al. 2021). The presence of nitrate from the application of chemical fertilizers is one of the important indicators of pollution of water resources, soil and crops (Wang et al. 2015).

According to the results obtained in this experiment, the heavier soil texture (silty clay) decreased the amount of nitrate leaching. The amount of nitrate leaching in control treatments in soil textures of sandy loam, silty clay loam and silty clay were 0.25, 0.22 and 0.2, respectively. An increased percentage of clay in the soil significantly reduces the amount of nitrate leaching. It seems that the entry of large amounts of N into the soil from chemical fertilizers and the inability of the crop to completely absorb it causes N loss that moves to deeper soils over time. Soils also contain ammonium ions due to the activity of the Urease enzyme. It produces a significant amount of nitrate, which due to its negative charge is not absorbed by soil particles. With irrigation and rainfall, the soil profile moves to a lower depth, and finally its concentration in the drainage sample will increase (Li et al. 2021). Increasing the amount of N uptake by the crop leads to less nitrate transfer to lower soil layers, thus reducing the leaching potential (Wang et al. 2015).

Analysis of variance for silty clay loam showed that applying N fertilizer at different times made a significant difference in grain yield for the two fertilizer sources. However, in the other two soil textures, the effect of the fertilizer source was not significant. Similar research shows that the use of AN changes the pH of the soil in the rhizosphere and thus changes its chemical properties. The changes in soil pH, depending on soil type—acidic or alkaline—may increase crop growth and increase the uptake of other nutrients (Wang et al. 2015; Wang et al. 2017). The results of this study follow the findings of Wang et al. (2015): The effect of N sources in different soil on grain yield varies; the effect of application time on grain yield and dry matter was also significant. The results vary in different soil types. In sandy loam and silty clay soil, the T_3 application time had the greatest effect on grain yield and dry matter. In silty clay loam, T_2 had the greatest impact on those variables. Research confirms that crop response to N varies depending on soil type, rainfall, rainfall distribution and growth stage (Soltani et al. 2006; Golba et al. 2013).

In general, N consumption is high in light soil texture and low in heavy soil texture. When wheat is alternated with legumes, N consumption reaches equilibrium meaning that N consumption will not affect grain yield and dry matter. N mineralization is also a way to increase usable N during the planting season. The amount needed varies between 60 kg per hectare for soil with a percentage of organic carbon less than 0.9 percent, and 100 kg per hectare for soil with a percentage of organic carbon more than 1.8 percent (Knowles and Doerge, 1991; Soltani et al. 2006). Perhaps if the N fertilizer was not used in the two experimental plots with heavy soil texture in the spring, the yield would be higher than the values obtained in this project. In other words, by not consuming N or reducing it in the spring, the same performance and maybe more could be achieved.

Conclusions

Based on the experimental results, the effect of N fertilizer on the protein percentage in the three groups of soil textures was significant at the level of one percent; the AN source had the greatest effect. Looking at wheat grain yield, the N fertilizer treatment was significant only in silty clay loam at the level of one percent, but in the other two soil groups was not significant. Silty clay loam with AN-T_1 at 11.1 percent and silty clay with AN-T_2 at 12.06 percent had the highest protein percentage. The important point here is that in two heavy soil textures (silty clay loam and silty clay), using AN fertilizer significantly increased the protein percentage of the wheat crop. The results showed that if AN fertilizer is used in any of the three soil types, the best time to apply it is T_2. Results will approximate what was found in this study: in sandy loam soil texture (nitrate leaching 0.3 mg l^{-1} and wheat grain yield 5981 kg ha^{-1}), in silty clay loam (leaching 0.32 mg l^{-1} and grain yield 6707 kg ha^{-1}) and in silty clay (nitrate leaching 0.3 mg l^{-1} and grain yield 6474 kg ha^{-1}). If NN fertilizer is used in any of the three soil types, the best time to apply it is $T_{3.}$ Results will approximate what was found in this study: in sandy loam soil texture (nitrate leaching 0.3 mg l^{-1} and grain yield 6302 kg ha^{-1}), in silty clay loam soil texture (nitrate leaching 0.36 mg l^{-1} and grain yield 6538 kg ha^{-1}) and in silty clay soil texture (nitrate leaching was 0.27 mg l^{-1} and grain yield is 6844 kg ha^{-1}).

Declarations

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Figures

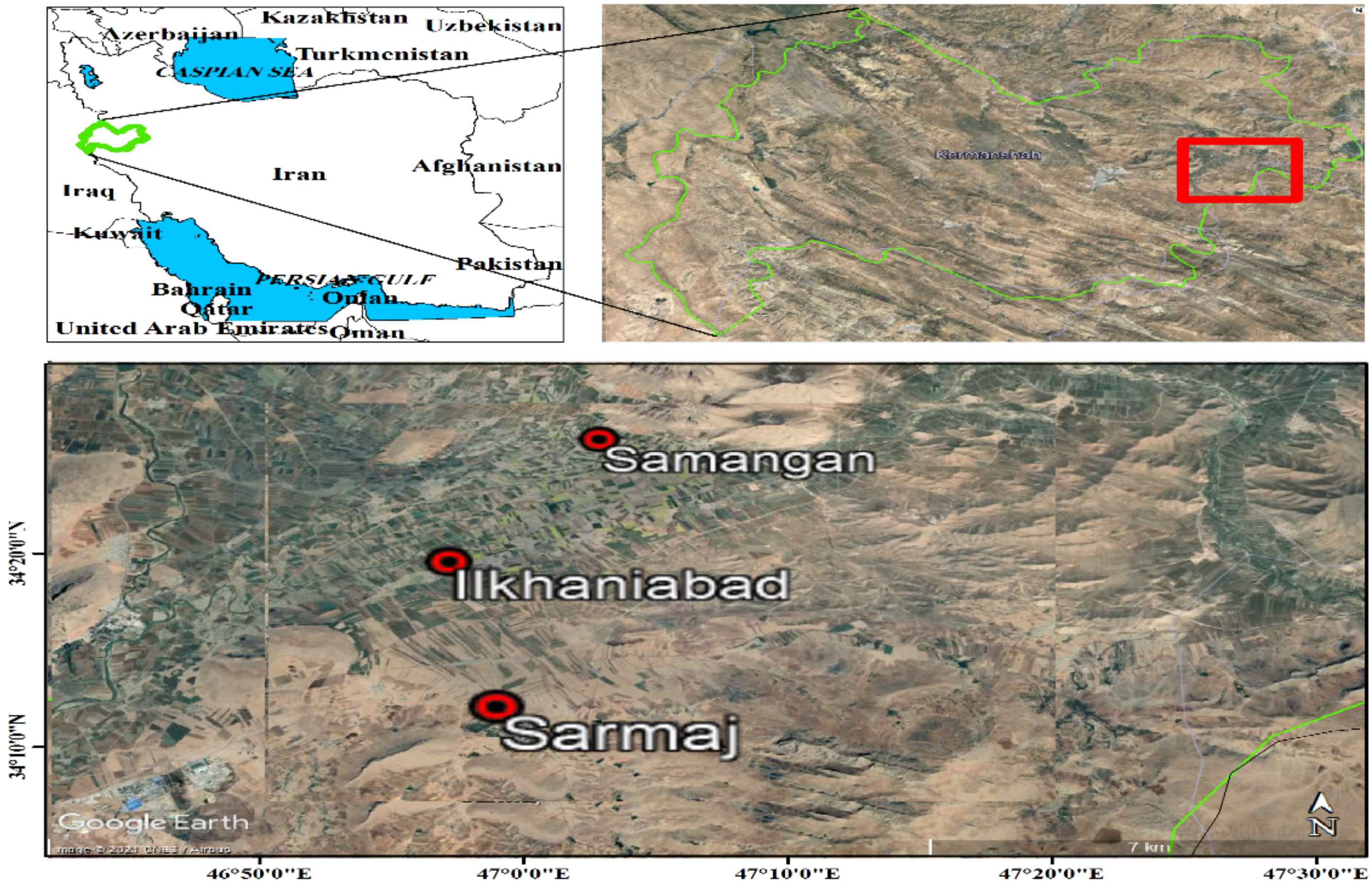

Figure 1

Geographical situation of the three experimental farms on the Bistoon Plain Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

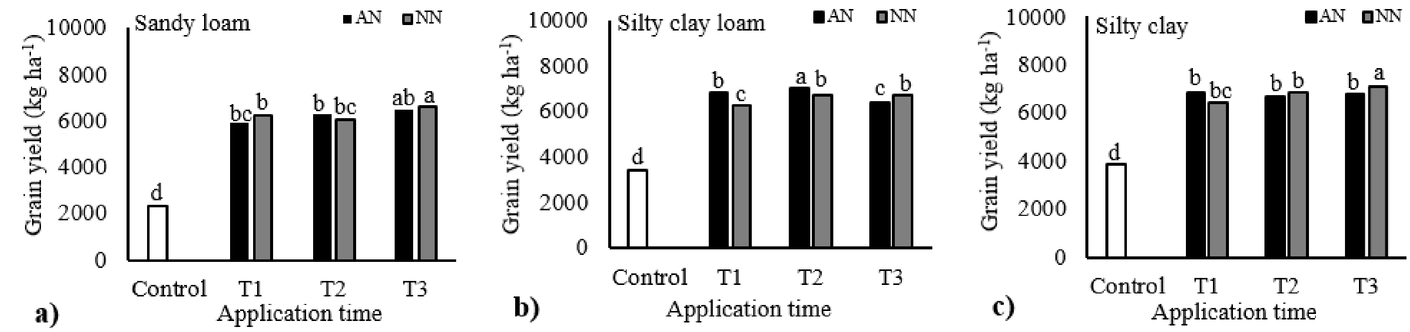

Figure 2

Effect of source and application time of N fertilizer on wheat grain yield in a) sandy loam, b) silty clay loam and c) silty clay soil textures

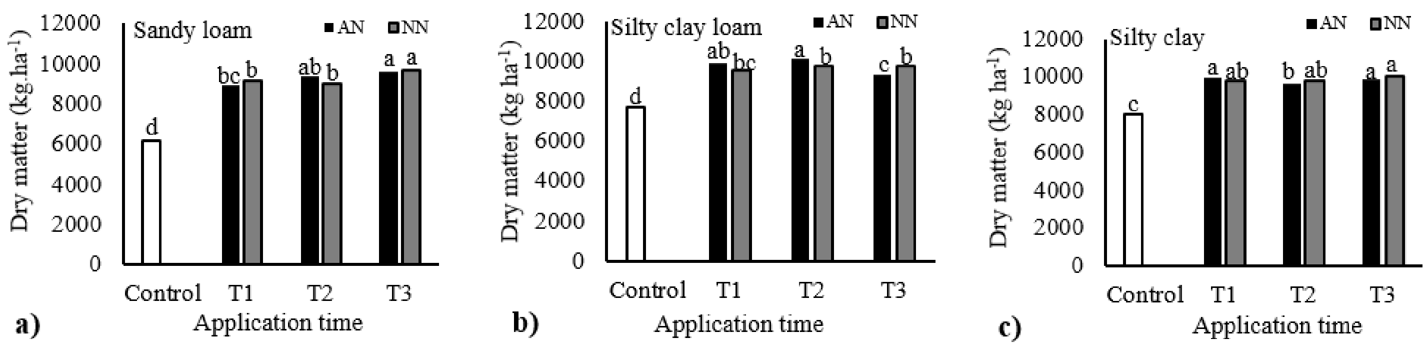

Figure 3

Effect of source and application time of N fertilizer on dry matter of wheat in a) sandy loam, b) silty clay loam and c) silty clay soil textures

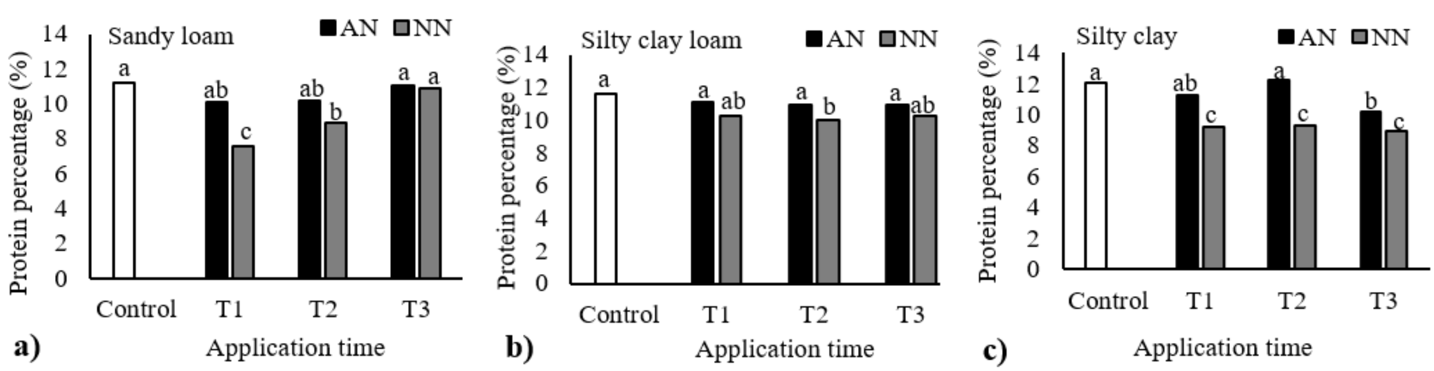

Figure 4

Effect of source and application time of N fertilizer on wheat protein percentage in a) sandy loam, b) silty clay loam and c) silty clay soil textures

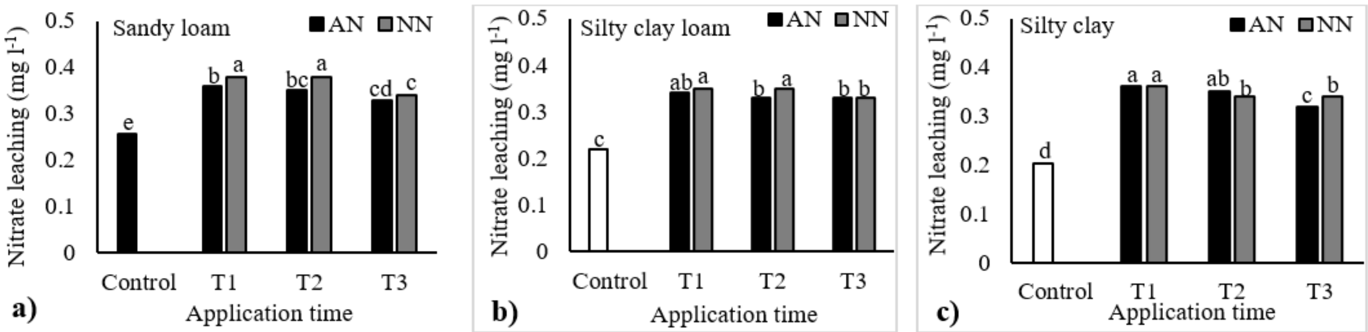

Figure 5

Effect of source and application time of N fertilizer on nitrate leaching in a) sandy loam, b) silty clay loam and c) silty clay soil textures

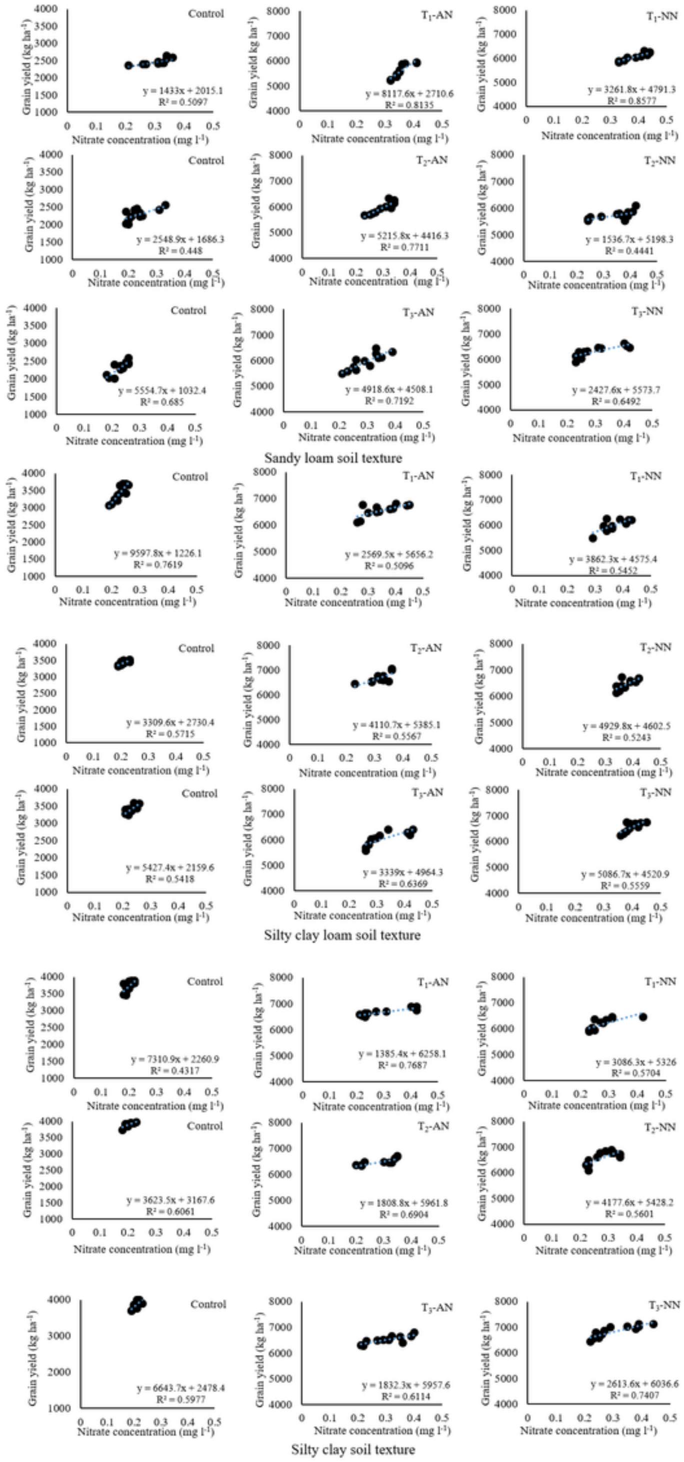

Figure 6

Wheat grain yield using AN and NN at different fertilizer application times in various soil textures