Nitrogen

Article

Nitrogen Use Efficiency Using the ^{15}N Dilution Technique for Wheat Yield under Conservation Agriculture and Nitrogen Fertilizer

Hassnae Maher [1,2,3,*], Rachid Moussadek [2,3], Abdelmjid Zouahri [2], Ahmed Douaik [2], Nour Eddine Amenzou [4], Moncef Benmansour [4], Hamza Iaaich [2], Houria Dakak [2], Zineb El Mouridi [2], Abdelkbir Bellaouchou [1] and Ahmed Ghanimi [1]

[1] Laboratory of Materials, Nanotechnologies, and Environment, Department of Chemistry, Faculty of Sciences, Mohammed V University in Rabat, Rabat P.O. Box 1014, Morocco; belbir@fsr.ac.ma (A.B.); a.ghanimi@um5r.ac.ma (A.G.)
[2] Research Unit on Environment and Conservation of Natural Resources, Regional Center of Rabat, National Institute of Agricultural Research, Rabat P.O. Box 6356, Morocco; rachid.moussadek@inra.ma or r.moussadek@cgiar.org (R.M.); abdelmjid.zouahri@inra.ma (A.Z.); ahmed.douaik@inra.ma (A.D.); hamza.iaaich@inra.ma (H.I.); houria.dakak@inra.ma (H.D.); zineb.elmouridi@inra.ma (Z.E.M.)
[3] International Center for Agricultural Research in Dry Areas (ICARDA), Rabat P.O. Box 2034, Morocco
[4] Division of Water and Climate, Direction of Studies and Scientific Research, National Center for Nuclear Energy, Sciences and Techniques (CNESTEN), Route de Kenitra-Mamoura, P.O. Box 1382, Kenitra 14000, Morocco; amenzou2002@yahoo.fr (N.E.A.); benmansour64@yahoo.fr (M.B.)
* Correspondence: hassnaemaher@gmail.com or hassnae_maher@um5.ac.ma or h.maher@cgiar.org; Tel.: +212-676612863

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Abstract: Conservation agriculture (CA), which could contribute to sustainable agriculture, maintains or improves soil nitrogen fertility by eliminating tillage (no-tillage). Quantitative assessment of soil constituents is enhanced by stable isotope techniques such as ^{15}N, which are used to better understand nitrogen dynamics. This study was therefore carried out to assess the impact of tillage type and fertilizer application on soil and plant nitrogen fractionation. The trial consisted of two tillage types: no-tillage (NT) and conventional tillage (CT). Three nitrogen doses (82, 115, and 149 kg ha^{-1}) were applied. The experimental design was a randomized complete block with three replications. The Louiza variety of durum wheat was used in this study. Soil nitrogen sequestration was assessed using the stable nitrogen isotope (^{15}N) method. The statistical analysis (ANOVA) showed that, overall, there was no significant difference between tillage types and nitrogen doses for grain and straw yields and grain total nitrogen. In contrast, the effect of both factors and their interaction were significant for straw total nitrogen. There was no difference between tillage types for grain nitrogen use efficiency (NUE), even though NT was superior to CT by 3.5%, but nitrogen doses had a significant effect and a significant interaction with tillage type. When comparing nitrogen doses for each tillage type separately, results showed that the average NUE for grain was 20.5, 8.4, and 16.5%, respectively, for the three nitrogen doses for CT compared with 26.8, 19.0, and 30.6% for NT, indicating clearly the better performance of NT compared to CT. Regarding straw, the NUE is 3.2, 3.5, and 5.4% for CT compared with 3.4, 4.9, and 9.2% for NT. NUE in grain and straw under no-tillage was higher than under conventional tillage in all three nitrogen doses. These results show that soil conservation techniques such as no-tillage and the integrated application of nitrogen fertilizer can be good strategies for reducing soil nitrogen losses.

Keywords: conventional tillage; durum wheat; nitrogen fertility; no-tillage; soil; stable isotope ^{15}N

1. Introduction

The importance of nitrogen (N) lies in its crucial role in improving the productivity and sustainability of agricultural, forest and pastoral lands [1–3]. Being an indispensable nutrient for all crop plants, cereals in particular require an adequate supply of nitrogen to ensure optimal growth, yield, and quality [4]. Not only the amount of nitrogen that is crucial but also the time of its supply to crops [5–7] and its splitting [8–10] are very important since all these three factors have a tremendous impact on the nitrogen use efficiency (NUE) [11–13].

The excessive use of nitrogen fertilizers in agriculture would have a significant impact on the environment, including water quality and biodiversity, mainly nitrates pollution of groundwaters [14–16], as well as might contribute to climate change by the emission of nitrous oxide [17–19].

To minimize the environmental impact of agricultural practices, new crop management methods have been developed. These include no-tillage, which involves sowing crops in undisturbed soil, without ploughing or turning the soil, leaving crop residues in the field and adopting crop rotation [20–22]. This agricultural technique offers a number of advantages, such as reducing costs and fuel consumption, as well as preserving soil quality [23–25], improving nitrogen levels [26–28], and increasing cereal crop yields [29–31].

Isotopes of chemical elements are largely used in crop production and land management. Fallout radionuclides (^{137}Cs, ^{7}Be, and ^{210}Pb) are used to assess the level and intensity of soil erosion [32–34]. The stable isotope ^{13}C can be used to monitor land degradation [35], as well as water availability [36,37] and soil organic carbon [38–40].

Regarding ^{15}N, it is a natural nitrogen isotope that is not radioactive and is present in varying quantities in the different types of nitrogen fertilizers used in agriculture. The stable isotope of nitrogen ^{15}N can be used in one of two possible forms: either enriched tracer or natural abundance. The nitrogen-stable isotope can be used to study the impact of agricultural practices on soil quality [41,42]. In particular, the ^{15}N natural abundance technique has also been successfully used to monitor the trajectory of nitrogen in landscapes [43,44] and to better understand nitrogen dynamics in different soils with different grown crops, such as maize [45,46], rice [47,48], vegetable crops [49,50], coffee [51], fodder crops [52,53], and wheat [54–56].

Several research works evaluated NUE under no-tillage without using ^{15}N for crops like eggplant, tomato, and wheat [57–59] while others used also ^{15}N, especially wheat [60–63]. Both types of studies were performed in different countries around the world.

To the best of our knowledge, although research on no-tillage began in our country in the early 1980s, no studies using ^{15}N have been conducted in Morocco. Therefore, to fill the research gap, we propose to use a fertilizer labeled with ^{15}N to determine the effects of nitrogen doses and two tillage types on wheat grain and straw yield, nitrogen derived from fertilizer, and nitrogen use efficiency in rainfed conditions.

2. Materials and Methods

2.1. Study Site

The experimental work was performed at the Marchouch experimental station of the National Institute of Agricultural Research (INRA) (Figure 1) located in the Zaer region, about 60 km south of Rabat, Morocco with the geographic coordinates 33°37 N, 6°43 W. This region has a Mediterranean climate influenced by the Atlantic Ocean. The average temperature is 28 °C and the average rainfall amounts to 400 mm. No-till has been practiced on the site since 2004, with the adoption of the cereal–legume rotation.

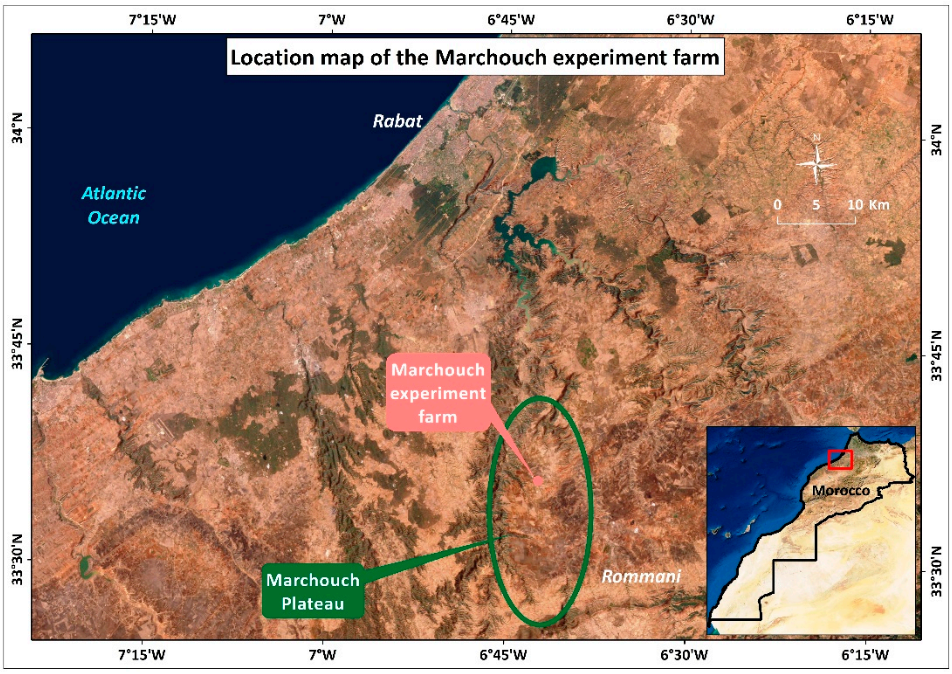

Figure 1. Location map of the Marchouch experimental station.

The soil is classified as a vertisol with a silty clay texture (47% clay, 42% silt, and 11% sand). Some chemical characteristics are given in Table 1. The soil at the study site has a neutral pH and is characterized by low organic matter, non-saline conditions, with a cationic exchange capacity of 42 meq/100 g, 0.132% nitrogen, 114 mg kg^{-1} of phosphorus, and 88 mg kg^{-1} of potassium.

Table 1. Soil chemical properties.

pH	OC (g kg^{-1})	Potassium (mg kg^{-1})	Phosphorus (mg kg^{-1})	CEC (meq/100 g)	EC (dS/m)	Ca (meq/100 g)	Mg (meq/100 g)	Nitrogen (%)
7.4	8.6	88.2	114.2	42.2	1.7	7.0	4.3	0.132

OC, organic carbon; CEC, cationic exchange capacity; EC, electrical conductivity.

2.2. Experimental Protocol

The experiment included two factors: tillage type with two levels (conventional tillage, CT and no-till, NT) and nitrogen dose with three levels (82, 115, and 149 kg ha^{-1}). A randomized complete block design was used with three replications. Conventional tillage was completed using a disc harrow at 10 to 15 cm depth to prepare seedbeds and bury residues followed by a chisel plow. In no-tillage, the soil was loosened by 2 to 3 cm to plant the seeds at a depth of 5 cm, using a special no-tillage drill. Two nitrogen fertilizers were used. First, the NPK 10-20-20 base fertilizer was applied at a rate of 150 kg ha^{-1} on 21 December 2020. One month later, the 33.5% ammonitrate fertilizer was supplied at 100 kg N ha^{-1} on 20 January 2021. On 8 February 2021 and 10 March 2021, 7.998, 6.337, and 4.541 g of ^{15}N were applied for the three nitrogen doses corresponding to 82, 115, and 149 kg ha^{-1}, respectively. These nitrogen doses were chosen such that we considered the recommended dose (115 kg ha^{-1}) and the one used by the farmers in the region (149 kg ha^{-1}). The smallest dose (82 kg ha^{-1}) was chosen as a less-than-optimal dose to have a constant difference between two consecutive doses (arithmetic progression or sequence), as recommended for optimizing quantitative factors during the statistical analysis.

The experiment used 18 experimental units, each having 10 m × 8 m = 80 m^2. Around each experimental unit, there were guard rows of 50 cm on each side; therefore, the whole experiment covered approximately 1500 m^2. To trace the fate of N fertilizer, ^{15}N-labeled (10.16%) was applied in each microplot of 2 m × 2 m = 4 m^2.

The crop used in the experimental work was durum wheat (*Triticum durum* Desf.), especially the Louiza (INRA-Maroc, 2011) variety. The cereal–legume rotation is practiced in the study site with lentils/chickpeas as the previous crop. Herbicides against dicotyledons and grasses were used for weed management. Two plots of one meter by one meter were selected and square metal rod quadrats were placed directly on the vegetation to determine grain and straw yields for each of the 18 experimental units. Plant samples were chopped and dried at 65 °C before grinding. Soil samples were sieved to 2 mm and then dried at 40 °C.

2.3. Climatic Data

Total rainfall and mean temperature for the growing season 2020–2021 as well as for 10 years (2013–2022) are shown in Figure 2. The pattern of mean temperature is almost the same for both time periods except for August and October, where the mean temperature was slightly lower for 2020–2021 compared to 2013–2022. In contrast, there is a drastic difference in the patterns of rainfall with very low levels for 2020–2021 compared to 2013–2022, but it rained only 6 months in 2020–2021 as opposed to 10 months for 2013–2022. These low rainfall amounts will have an impact on the grain and straw yield of wheat.

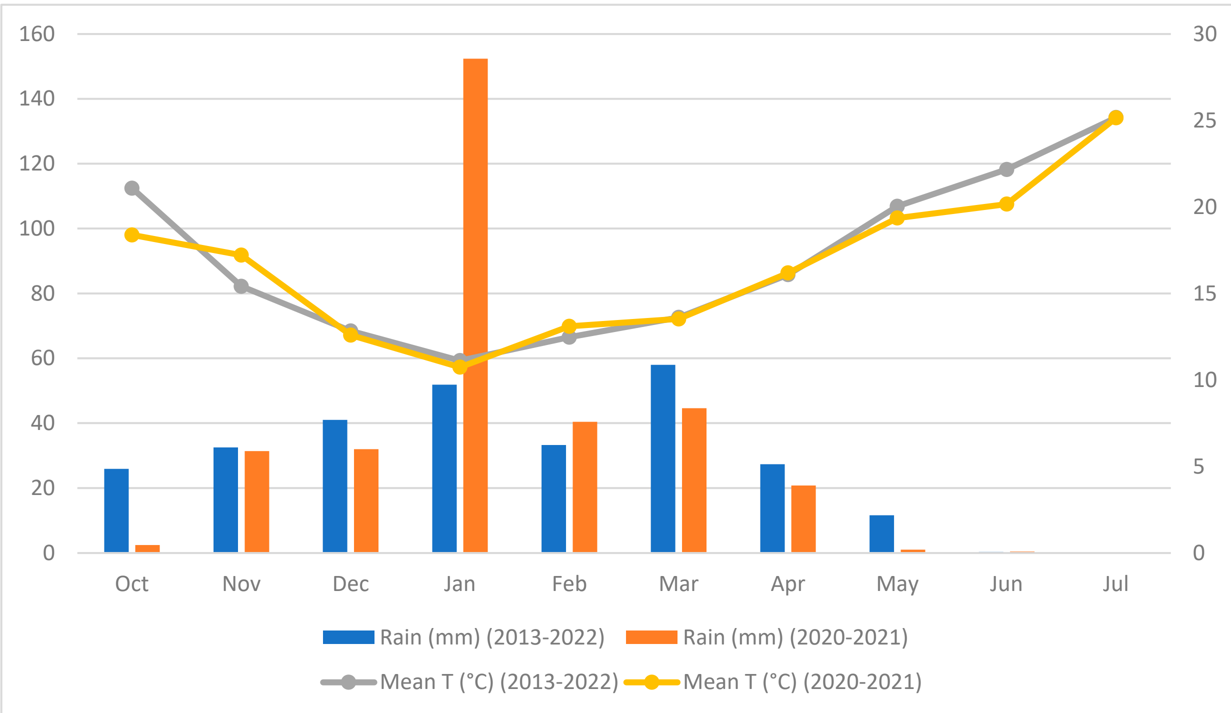

Figure 2. Contrasting rainfall and temperature in the Zaër Region: 2020–2021 season in comparison to the 10-year average (2013–2022) at the Marchouch experimental station.

2.4. Stable Isotope Analysis

^{15}N and total nitrogen analyses were performed at the National Center for Nuclear Energy, Science, and Technology (CNESTEN, Rabat, Morocco). The abundance of δ^{15}N isotopes from the wheat grain and straw (5 to 6 mg of samples) was determined by EA-IRMS using an isotope ratio mass spectrometer (Delta V Thermo Scientific, Germany) coupled to an element analyzer (Thermo Scientific FLASH HT Plus, Waltham, MA, USA) following the procedure described by Mariotti [64]. The grain and straw materials were oven-dried at 70 °C for 24 h, ground separately, and transferred into small tin capsules in an element analyzer tray. The stable isotope ratios were expressed in delta (δ) kg and a permil (%) notation relative to an international standard [65]:

$$\delta \mathrm{AX}(‰) = \left(\frac{R_{Sample}}{R_{Standard}} - 1 \right) \times 1000 \quad (1)$$

δ^{A}X expresses the abundance of isotope A of element X in a sample relative to the abundance of that same isotope in a reference material. R_{sample} and $R_{standard}$ are the $^{15}N/^{14}N$ ratios of the sample and sample standard for δ^{15}N. Values of δ^{15}N are reported relative to N_2 in atmospheric air (AIR).

The isotopic δ^{15}N (‰) values of the samples were calibrated versus the certified reference materials Leuncin (δ^{15}N (‰) = 10.4 ± 0.5‰) and Caffeine IAEA-600 (δ^{15}N (‰) = 1.0 ± 0.2‰). Uncertainty per batch (7 replicates of secondary isotopic reference material) was ≤1.5‰ for δ^{15}N.

Percent nitrogen derived from fertilizer (%NDFF), nitrogen derived from fertilizer (NDFF kg ha^{-1}), and nitrogen use efficiency (NUE) were calculated as follows [66]:

$$\%NDFF = \frac{Atom\ \%\ 15\ N\ axcess\ in\ crop}{Atom\ \%\ 15\ N\ axcess\ in\ fertilizer} \times 100 \quad (2)$$

$$NDFF\left(kgha^{-1}\right) = \frac{\%NDFF}{100} \times totalN\left(kgha^{-1}\right) \quad (3)$$

$$NUE\ (\%) = \left(\frac{amount\ of\ N\ derived\ from\ fertilizer}{amount\ of\ N\ applied\ as\ fertilizer} \right) \times 100 \quad (4)$$

where NDFF represents nitrogen derived from fertilizer (kg ha^{-1}), i.e., amount of nitrogen derived from fertilizer; NUE represents nitrogen use efficiency (%).

2.5. Statistical Analysis

Mean, standard deviation, minimum, and maximum were computed for wheat grain and straw yields, plant total nitrogen, nitrogen derived from fertilizer (NDFF), and nitrogen use efficiency (NUE). As data followed normality (checked by the Shapiro–Wilk test) and had equal variances (checked by the Levene test), the analysis of variance (ANOVA) was used to compare the means corresponding to the main effects of the two factors (the two tillage types and the three nitrogen doses) and, eventually, their interactions. In case of significant effects of the factors, the Tukey HSD post-hoc test was used to compare each pair of levels of both factors. A significance level of 5% was adopted for all statistical tests. Effect sizes (partial eta squared), giving the magnitude of the effects or their practical significance or biological relevance, were also reported [67,68], which can be used, subsequently, in meta-analysis [69–71]. The SPSS software, version 25 (IBM Corp., Armonk, NY, USA), was used for all computations.

3. Results and Discussion

3.1. Grain and Straw Yields

Mean grain yields were very similar and varied between 3.1 and 3.3 t ha^{-1} while those for straw yield ranged between 6.3 and 6.9 t ha^{-1} (Table 2). The ANOVA results showed that, overall, there were no statistically significant differences between both tillage types and the three nitrogen doses nor any interaction between these two factors for both wheat grain and straw yields (all *p*-values are much higher than the significance level of 0.05). This is confirmed by the effect sizes that are either nil (<0.010), small (0.010–0.059), or medium (0.059–0.138).

Table 2. ANOVA results for wheat grain and straw yields and total nitrogen: means, standard deviations, *p*-values, and effect sizes.

Factors	Levels/Effects	Yield (t ha^{-1})		Plant Total Nitrogen (g kg^{-1})	
		Grain	Straw	Grain	Straw
Tillage	CT	3.19 ± 0.42	6.27 ± 1.39	31.00 ± 05.12	3.80 ± 1.26 b
	NT	3.17 ± 0.52	6.88 ± 0.82	39.14 ± 15.18	5.58 ± 1.19 a
Nitrogen (kg ha^{-1})	82	3.32 ± 0.48	6.47 ± 1.17	35.01 ± 11.47	3.96 ± 1.25
	115	3.14 ± 0.59	6.73 ± 1.35	30.28 ± 09.27	4.70 ± 1.81
	149	3.09 ± 0.32	6.53 ± 1.11	39.94 ± 14.03	5.42 ± 1.23
p-value	Tillage (T)	0.961	0.311	0.103	0.005
	Nitrogen (N)	0.718	0.929	0.269	0.108
	T*N	0.506	0.432	0.072	0.299
Effect size	Tillage (T)	0.0002	0.085	0.206	0.499
	Nitrogen (N)	0.054	0.012	0.197	0.310
	T*N	0.107	0.130	0.355	0.182

CT, conventional tillage; NT, no-tillage. Factor levels with different, either lowercase or uppercase, letters are significantly different based on the Tukey HSD post-hoc test.

3.2. Plant Total Nitrogen Contents

Based on the ANOVA results (Table 2), there was a significant difference only between the two tillage types for wheat straw yield (*p*-value = 0.005, which is much lower than the significance level of 0.05) with a higher mean value for NT (5.6 g kg^{-1}) compared to CT (3.8 g kg^{-1}). All effect sizes are large (>0.138) with the largest (0.499) corresponding to the only significant effect of tillage type on wheat straw yield. Although there was no significant difference between the two tillage types regarding grain yield (*p*-value = 0.103), the two mean values are quite different with an additional total nitrogen of 8.1 g kg^{-1} or 26.3% for NT compared to CT. This is confirmed by a large effect size (0.206). The non-significance could be explained by the high variability of the three replications for NT (with a standard deviation of 15.2 g kg^{-1} against 5.1 g kg^{-1} for CT). The same remark can be made for the effect of nitrogen dose on straw yield with a difference of 1.5 g kg^{-1} or 36.9% in favor of 149 kg ha^{-1} compared to 82 kg ha^{-1} which is confirmed by the third largest effect size (0.310).

3.3. Nitrogen Derived from Fertilizer

Regarding grain NDFF, only the nitrogen dose effect was statistically significant (*p*-value = 0.021) with a large effect size (0.474) and a mean value of 26.7% corresponding to a supply of 149 kg ha^{-1} much higher compared to 19.3 and 18.0% corresponding to 115 and 82 kg ha^{-1}, respectively (Table 3). Wan, X.J. et al. showed a sharper increase in NDFF with nitrogen dose as they used much higher doses (0, 120, 240, and 360 kg ha^{-1}) than our study and considered both rainfed and irrigated fields [54].

Both the two main effects and their interaction were statistically significant for straw NDFF (all *p*-values were lower than 0.05) with large effect sizes of 0.315 and 0.892 for tillage type and nitrogen dose, respectively. Mean values were higher for NT (19.0%) compared to CT (15.7%) and increased with the supplied amount of nitrogen (10.1% for 82 kg ha^{-1} to 27.0% for 149 kg ha^{-1}).

Table 3. ANOVA results for nitrogen derived from fertilizer (NDFF) and nitrogen use efficiency (NUE): means, standard deviations, *p*-values, and effect sizes.

Factors	Levels/Effects	NDFF (%)		NUE (%)	
		Grain	Straw	Grain	Straw
Tillage	CT	22.00 ± 5.92	15.69 ± 05.11 b	18.64 ± 03.78	3.77 ± 1.29 b
	NT	20.63 ± 6.43	19.04 ± 11.01 a	22.08 ± 10.82	5.81 ± 2.98 a
Nitrogen (kg ha^{-1})	82	18.02 ± 6.01 B	10.10 ± 02.86 C	23.62 ± 05.94 A	3.43 ± 0.48 B
	115	19.26 ± 4.95 B	15.00 ± 04.08 B	13.90 ± 06.79 B	4.16 ± 1.77 B
	149	26.67 ± 3.27 A	27.00 ± 06.29 A	23.55 ± 08.03 A	6.78 ± 3.14 A
p-value	Tillage (T)	0.565	0.037	0.110	0.015
	Nitrogen (N)	0.021	<0.001	0.002	0.006
	T*N	0.337	0.004	0.001	0.042
Effect size	Tillage (T)	0.028	0.315	0.199	0.403
	Nitrogen (N)	0.474	0.892	0.636	0.571
	T*N	0.166	0.596	0.683	0.411

CT, conventional tillage; NT, no-tillage; NDFF, nitrogen derived from fertilizer; NUE, nitrogen use efficiency. Factor levels with different, either lowercase or uppercase, letters are significantly different based on the Tukey HSD post-hoc test.

As the tillage type and nitrogen dose interaction was statistically significant (*p*-value = 0.004) with a large effect size (0.596) and looking for more insight into straw yield, we compared the two tillage types for each nitrogen dose separately and the three nitrogen doses for each tillage type (Figure 3). The straw NDFF differed significantly (*p*-value < 0.001) between the two tillage types only at 149 kg ha^{-1} with a higher value (32.7%) for NT compared to 21.3% for CT (Figure 3, lowercase letters). Regarding the separate analysis by tillage type (Figure 3, uppercase letters), straw NDFF differed significantly between the three nitrogen doses for both tillage types (*p*-value = 0.020 for CT and less than 0.001 for NT). For CT, straw NDFF increased with increasing nitrogen amount from 11.7 to 21.3% for supplied nitrogen of 82 to 149 kg ha^{-1}, whereas the increase was much stronger for NT (from 8.5 to 32.7% for the same supplied nitrogen amounts as mentioned above).

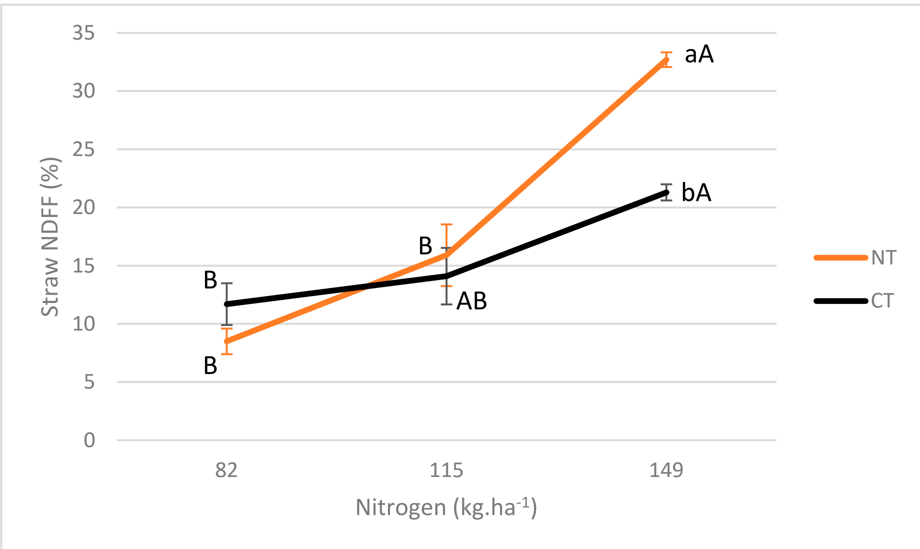

Figure 3. Wheat straw NDFF (%). CT, conventional tillage; NT, no-tillage; NDFF, nitrogen derived from fertilizer. Vertical bars represent standard errors. Tillage types with different lowercase letters are significantly different based on the Tukey HSD post-hoc test for each nitrogen dose. Nitrogen doses with different uppercase letters are significantly different based on the Tukey HSD post-hoc test for each tillage type.

3.4. Nitrogen Use Efficiency

Nitrogen dose and its interaction with tillage type were statistically significant for grain NUE (p-values = 0.002 and 0.001, respectively) and both factor effects and their interaction were statistically significant for straw NUE (p-values = 0.015, 0.006, and 0.042, for tillage type, nitrogen dose, and their interaction, respectively) (Table 3). Straw NUE was higher in NT (5.8%) compared to CT (3.8%) and increased with the amount of supplied nitrogen (from 3.4% for 82 kg ha^{-1} to 6.8% for 149 kg ha^{-1}). Grain NUE was similar for the lowest nitrogen doses (23.6%) and much higher compared to the medium nitrogen dose (13.9%). Ref. [28] found a significant difference between the nitrogen doses (0, 45, 90, and 135 kg ha^{-1}) but with NUE values decreasing with nitrogen doses. The only non-significant factor is tillage type for grain NUE, even if NT has an additional 3.5% in comparison to CT and this factor has a large effect size (0.199). As for grain total nitrogen, this is probably due to the high variability in grain NUE with a standard deviation of 10.8% for NT compared to 3.8% for CT. Ref. [57] found a significant difference between the two tillage types, even though there were higher NUE values (28.7 and 25.8% compared to 22.1 and 18.6% in our study, for NT and CT, respectively) but with a lesser magnitude in difference in favor of NT (2.9% compared to 3.5% in our study). Also, Ref. [28] found a significant difference between the two tillage types with a much higher NUE value for NT compared to CT (an average difference of 9.8% between both tillage types).

Since interaction was statistically significant for both grain and straw NUE with large effect sizes of 0.683 and 0.411, respectively, we did two separate analyses comparing one factor for each level of the other factor. Regarding grain NUE, there was a significant difference between the two tillage types at 115 and 149 kg ha^{-1} (p-values = 0.047 and 0.002, respectively) but not at 82 kg ha^{-1} (p-value = 0.226) (Figure 4). The pattern was not the same at these two nitrogen doses: Higher grain NUE was found under CT at 115 kg ha^{-1} (19.0% against 8.8%) but under NT at 149 kg ha^{-1} (30.6% against 16.5%). The three nitrogen doses differed significantly at NT (p-value = 0.002) but not at CT (p-value = 0.485). The grain NUE mean values under NT followed the same pattern found in the overall analysis with similarly high values at the lowest and highest nitrogen doses (26.8 and 30.6%, respectively) that differed significantly from the intermediate dose with a low value (8.8%). This can be explained by the soil dry condition that occurred during the second application of N in the mid-season (February 8), which affected the NUE since there was little rainfall at this time (Figure 2). This was not the situation for the lowest and the highest nitrogen doses as these two doses were applied during favorable climatic conditions, in particular, rainfall. This is in line with studies carried out in Morocco, which reported that NUE in wheat is highly linked to rainfall distribution in semi-arid conditions [72,73]. The lower average grain NUE for 115 kg N ha^{-1} may be explained by the fact that there was a small amount of rainfall when the second fertilizer application was made (Figure 2). It then increases at 149 kg N ha^{-1}, which is in line with studies that have shown that the stable isotope values of nitrogen in plants are affected by rainfall [74]. Initially, it is essential to optimize the N rates considering both soil fertility and crop requirements. Once optimized, these rates should be applied using suitable methods and timed appropriately, taking into account the specific soil properties and prevailing climatic conditions [75,76]. For straw NUE, a significant difference between the two tillage types was observed only at the highest nitrogen dose (p-value = 0.033) but not at the two other doses (p-values = 0.830 and 0.400, for 82 and 115 kg ha^{-1}, respectively) with a higher value (9.2%) under NT compared to 4.3% under CT (Figure 5). As for grain, there was a significant difference in straw NUE between the three nitrogen doses only at NT (p-value = 0.012) but not CT (p-value = 0.694). The straw NUE values increased with the nitrogen doses from 3.4 to 9.2%.

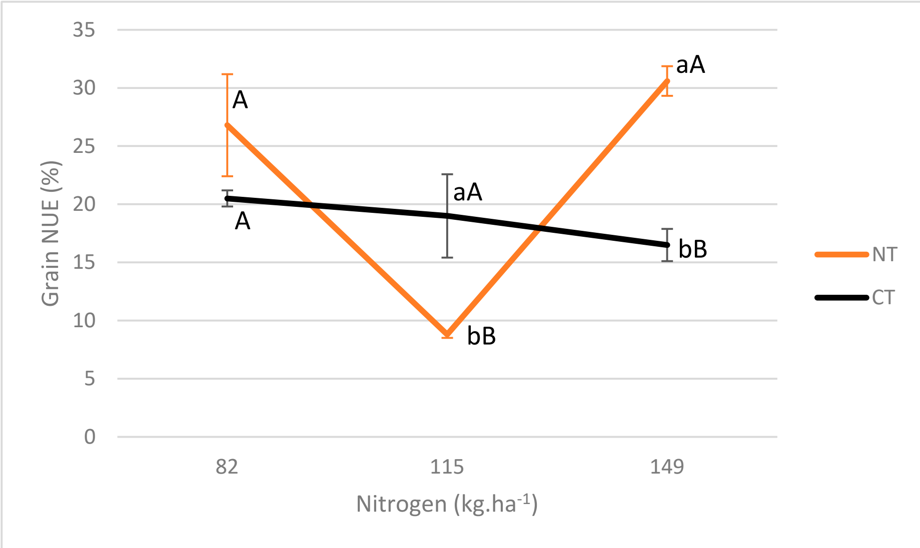

Figure 4. Wheat grain NUE (%). CT, conventional tillage; NT, no-tillage; NUE, nitrogen use efficiency. Vertical bars represent standard errors. Tillage types with different lowercase letters are significantly different based on the Tukey HSD post-hoc test for each nitrogen dose. Nitrogen doses with different uppercase letters are significantly different based on the Tukey HSD post-hoc test for each tillage type.

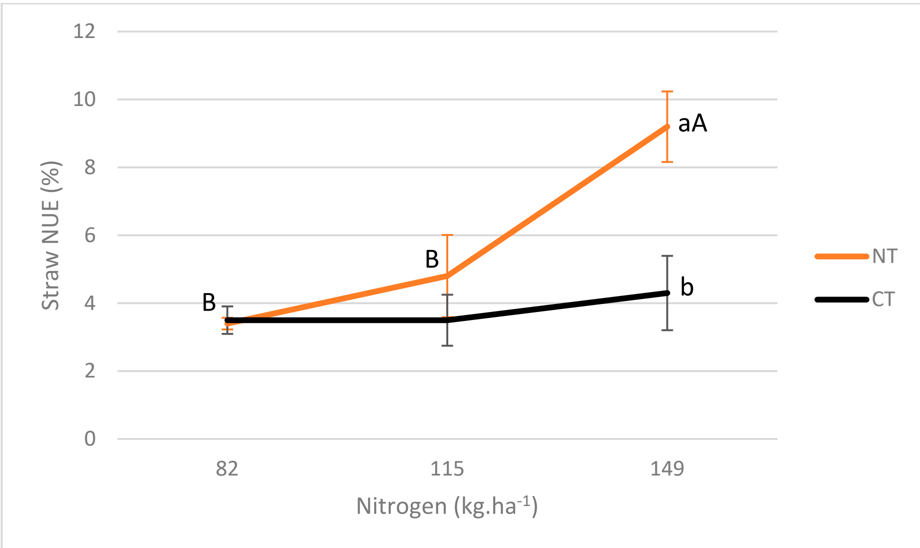

Figure 5. Wheat straw NUE (%). CT, conventional tillage; NT, no-tillage; NUE, nitrogen use efficiency. Vertical bars represent standard errors. Tillage types with different lowercase letters are significantly different based on the Tukey HSD post-hoc test for each nitrogen dose. Nitrogen doses with different uppercase letters are significantly different based on the Tukey HSD post-hoc test for each tillage type.

The average NUE in NT is higher than that in CT for grain and straw yields. Therefore, no-tillage could contribute to environmental conservation through a reduction in nitrate leaching in the soil [77] if adopted.

The increase in yield observed with no-tillage practices and the response of yield to varying fertilizer levels can be attributed to the improved N and NUE yield resulting from better use of nitrogen and consequently reduced soil nutrient deficiencies. The impact of tillage and fertilizers on wheat grain yield varies due to differences in soil conditions [78], water availability, and rainfall patterns [79], as well as the specific tillage and fertilizer levels used [80]. Many researchers [81–83] have suggested that the crop response to tillage depends on several interacting factors, such as the crop species, soil, and climatic conditions.

Furthermore, Ref. [84] reported that no-till practices also increase soil moisture retention and enhance water use efficiency in crops.

4. Conclusions

This study was carried out to assess the impact of tillage and fertilizer application on nitrogen distribution in soil and durum wheat (Louiza variety). Two tillage types were compared: no-till (NT) and conventional tillage (CT) using three nitrogen doses (82, 115, and 149 kg N ha^{-1}). Soil nitrogen content was assessed using the stable nitrogen isotope method (^{15}N). ANOVA showed that there was no significant difference between tillage types and nitrogen doses for grain and straw yields and grain total nitrogen. The effects of both factors and their interaction were significant for straw total nitrogen. There was no difference between tillage types for grain nitrogen use efficiency (NUE), even though NT was superior to CT by 3.5%, but nitrogen doses had a significant effect and a significant interaction with tillage type. The results of the separate analysis of nitrogen doses for each tillage type showed that the average NUE for grain was 20.5, 8.4, and 16.5%, respectively, for the three nitrogen doses in the case of CT, while it was 26.8, 19.0, and 30.6% for NT. This indicates that NT outperformed CT. For straw, NUE was 3.2, 3.5, and 5.4% for CT and 3.4, 4.9, and 9.2% for NT, for the same nitrogen doses. The results highlight a higher NUE for grain and straw under no-till compared to conventional tillage, at all three nitrogen doses. Conservation agriculture practices, such as no-till, could be an effective strategy for reducing soil nitrogen losses. In conclusion, a no-tillage system should be promoted as one of the best practices to enhance the NUE, productivity, and quality of durum wheat under semi-arid conditions. Establishing a model linking these variations with N input rates could offer a promising approach to better understanding and predicting fertilizer N uses and losses, in order to precisely optimize N management practices under conservation agriculture.

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