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THESIS

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NITROGEN USE EFFICIENCY IN DURUM WHEAT (*Triticum durum* desf.) GROWN IN SEMI-ARID ZONE: PHYSIOLOGICAL ANALYSIS AND GENETIC DETERMINISM

Presented by By BENCHELALI Soumia

Jury

President	Pr. LARIBI. Abdelkader-Professor (E.N.S.A El-Harrach, Alger)
Supervisor	Pr. MEFTI. Mohamed- Professor (E.N.S.A El-Harrach, Alger)
Examiner	Pr. BENMAHAMMED. Amar-Professor (University of Sétif 1)
Examiner	Dr. LEBBAL. Salim-MCA(University of Khenchela)

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DEDICATION

First and foremost, thanks to Allah the most graceful and merciful for his showers
of blessings throughout my research work to complete it successfully

I express a special feeling of gratitude to my loving parents, Ahmed and Fatima, who have always loved me unconditionally and set good examples that taught me to work hard for my aspirations.

This thesis is dedicated to:

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My dear sisters: Samira, Naziha, Karima, Hadjer, Khaoula, and Assia, whose unwavering support has meant the world to me.
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خلاصة البحث

تعتبر الإدارة السليمة والمستدامة للتخصيب بالنيتروجين واحدة من أكثر مشاكل زراعة الحبوب شيوعًا في المناطق شبه الجافة ، والتي تتميز بتنوع كبير في الظروف المناخية. تم إجراء العمل الحالي لتقييم آثار التسميد بالنيتروجين على الجوانب الزراعية والاقتصادية للقمح الصلب المزروع في ظل ظروف شبه جافة في الجزائر ولتحديد كفاءة استخدام النيتروجين بين سبعة اصناف وراثية منتشرة في البلاد (طويل وقصير. القديمة والحديثة) ولتقييم تأثير الظروف الجوية (إجمالي هطول الأمطار في الفترة الخضرية ، وإجمالي هطول الأمطار في فترة التزهير والتعبئة ومتوسط درجة الحرارة) على محصول الحبوب و NUE في بيئتين متباينتين (الجزائر وإيطاليا).

الأنماط الجينية السبعة: Bousselam, Waha, MBB, Sétifis, Megress, Massinissa and Gtadur تم فحصها تحت أربعة جرعات نيتروجين من صفر إلى 120 وحدة نتروجين في هكتار خلال اربع مواسم زراعية (2016 إلى 2019). تشير النتائج إلى أن امتصاص النيتروجين الكلي عند النضج ، وامتصاص النيتروجين من طرف الحبوب ، ومؤشر حصاد النيتروجين ، وكفاءة استخدام النيتروجين ومكوناته ، مثل كفاءة امتصاص النيتروجين وكفاءة استخدام النيتروجين ، تأثرت معنويا بالسنة والصنف الوراثي ومستوى النيتروجين. من هذه الدراسة ، يبدو أن جرعات النيتروجين المرتفعة أدت إلى تحسين امتصاص النيتروجين الكلي عند النضج وامتصاص النيتروجين بواسطة الحبوب. ومع ذلك ، لم يلاحظ أي تأثير على محصول الحبوب ؛ وعلى العكس من ذلك ، أدت زيادة مستويات النيتروجين إلى انخفاض بنسبة 12٪ في العائد الاقتصادي. بمعنى آخر ، في بيئة شمال إفريقيا ، تكون الاستجابة للنيتروجين أكثر وضوحًا علي الجودة من مردود المحصول ، والذي يعتمد بدوره على الظروف الجوية السنوية و الاصناف الجينية المزروعة. علاوة على ذلك ، يؤثر النيتروجين سلبًا على كفاءة استخدام النيتروجين ومكوناته. في المتوسط ، أظهرت كفاءة استخدام النيتروجين قيمًا منخفضة (14.77 كجم كجم -1) ، معظمها غير منتظمة وتعتمد بشكل كبير على الظروف الجوية ؛ في أفضل عام لم يتجاوز 60٪ (19.87 كغ كغ -1) من المتوسط العالمي لقيمة 33 كغ كغ -1. علاوة على ذلك ، أظهرت الاصناف الوراثية الحديثة (طويل القامة) و (قصيرة) Megress GTAdur أفضل قدرة على تحمل ظروف النيتروجين المختلفة ونقص المياه ، مما يوفر .استخدام فعال للنيتروجين من الأسمدة والتربة أكثر من النوعين الجينيين الآخرين.

كان لإجمالي هطول الأمطار في الفترة الخضرية (RVP) التأثير الأكبر على كل من محصول الحبوب وكفاءة استخدام النيتروجين (NUE). أدى هطول الأمطار الكافية خلال هذه المرحلة إلى تحسين كفاءة امتصاص (NUpE) وكفاءة استخدام(NUtE) ، مما أدى إلى ارتفاع NUE.

ممفاتيح البحث: القمح الصلب؛ تسميد النيتروجين؛ كفاءة استخدام النيتروجين ؛ كفاءة امتصاص النيتروجين ؛ كفاءة استخدام النيتروجين ، الظروف الجوية.

ABSTRACT

The proper and sustainable management of nitrogen fertilization is one of the most common problems of cereal cultivation in semiarid regions, which are characterized by a wide variability in climatic conditions. The current work was conducted to evaluate the effects of nitrogen fertilization on the agronomic and economic aspects of durum wheat cultivated under rainfed semiarid conditions in Algeria and to determine the most efficient nitrogen use efficiency (NUE) among seven genotypes that are widespread in the country (tall and short, old and modern genotypes), and to evaluate the effect of weather conditions (the total rainfall at vegetative period, the total rainfall at flowering and filling period and the mean temperature) on grain yield and NUE under two contrast environments (Algeria and Italy) .

The seven genotypes, Bousselam, Waha, MBB, Sétifis, Megress, Massinissa and Gtadur were investigated under four nitrogen rates from 0 to 120 uN ha-1 during three cropping seasons (2016 to 2019). The results indicate that the total nitrogen uptake at maturity (NM), nitrogen uptake by grain (NG), nitrogen harvest index (NHI), NUE and its components, such as nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE), were significantly affected by year, genotype, and nitrogen level.

From this study, it appears that higher nitrogen rates improved NM and NG. However, no effects on grain yield were observed; conversely, increased nitrogen levels produced a 12% reduction in the economic return. In other words, in the North African environment, the response to nitrogen is more evident in quality than in yield, which in turn is dependent on the yearly weather conditions and cultivated genotypes. Moreover, nitrogen negatively affected NUE and its components (NUpE, NUtE). On average, NUE displayed low values (14.77 kg kg-1), mostly irregular and highly dependent on weather conditions; in the best year, it did not exceed 60% (19.87 kg kg-1) of the global average value of 33 kg kg-1. Moreover, the modern genotypes Megress (tall) and GTAdur (short) showed the best capacity to tolerate different nitrogen conditions and water shortages, providing relatively superior yields, as well as more effective N use from fertilizers and the soil than the other two genotypes.

The total rainfall at the vegetative period (RVP) had the most significant effect on both grain yield and nitrogen use efficiency (NUE). Adequate rainfall during this phase improved N uptake efficiency (NUpE) and N utilization efficiency (NUtE), leading to higher NUE.

Keywords: durum wheat; nitrogen fertilization; nitrogen use efficiency; nitrogen uptake efficiency; nitrogen utilization efficiency, weather conditions.

RESUME

La gestion correcte et durable de la fertilisation azotée est l'un des plus problèmes communs de la céréaliculture dans les régions semi-arides, qui se caractérisent par une large variabilité des conditions climatiques. Le présent travail a été mené pour évaluer les effets de la fertilisation azotée sur les aspects agronomiques et économiques du blé dur cultivé en conditions semi-arides pluviales en Algérie et pour déterminer l'efficacité d'utilisation de l'azote (NUE) chez sept génotypes répandus dans le pays (longs et courts, génotypes anciens et modernes) et évaluer l'effet des conditions météorologiques (la pluviométrie totale pendant la période végétative, la pluviométrie totale pendant la période de floraison et de remplissage, ainsi que la température moyenne) sur le rendement en grains et l'efficience d'utilisation de l'azote (NUE) dans deux environnements contrastés (Algérie et Italie).

Les sept génotypes, Bousselam, Waha, MBB, Sétifis, Megress, Massinissa et GTAdur, ont été cultivés sous quatre taux d'azote de 0 à 120 uN ha-1 pendant trois saisons culturales (2016 à 2019). Les résultats indiquent que l'absorption totale d'azote à maturité (NM), l'absorption d'azote par le grain (NG), l'indice de récolte d'azote (NHI), le NUE et ses composants, tels que l'efficacité d'absorption d'azote (NUpE) et l'efficacité d'utilisation de l'azote (NUtE), étaient significativement affectés par l'année, le génotype et le niveau d'azote.

De cette étude, il ressort que des taux d'azote plus élevés ont amélioré NM et NG. Cependant, aucun effet sur le rendement en grains n'a été observé; à l'inverse, l'augmentation des niveaux d'azote a produit une réduction de 12% du rendement économique. En d'autres termes, dans l'environnement nord-africain, la réponse à l'azote est plus évidente dans la qualité que dans le rendement, qui à son tour dépend des conditions météorologiques annuelles et des génotypes cultivés. De plus, l'azote a eu un effet négatif sur le NUE et ses composants (NUpE, NUtE). En moyenne, le NUE affiche des valeurs faibles (14,77 kg kg-1), le plus souvent irrégulières et fortement dépendantes des conditions météorologiques ; la meilleure année, elle ne dépassait pas 60 % (19,87 kg kg-1) de la valeur moyenne mondiale de 33 kg kg-1. De plus, les génotypes modernes Megress et GTAdur ont montré la meilleure capacité à tolérer différentes les conditions d'azote et les pénuries d'eau, fournissant des rendements relativement supérieurs, ainsi que plus utilisation efficace de l'azote des engrais et du sol que les deux autres génotypes.

La pluviométrie totale à la période végétative (RVP) a eu l'effet le plus significatif à la fois sur le rendement en grain et sur l'efficacité d'utilisation de l'azote (NUE). Des précipitations adéquates au cours de cette phase ont amélioré l'efficacité d'absorption de N (NUpE) et l'efficacité d'utilisation de N (NUtE), conduisant à une NUE plus élevée.

Mots clés : blé dur ; fertilisation azotée; efficience d'utilisation de l'azote; efficacité d'absorption d'azote ; efficacité d'utilisation de l'azote conditions météorologiques.

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LIST OF ABBREVIATIONS

AL	Awns length
ANCOVA	Analysis of CoVariance
ANOVA	Analysis of Variance
CCI	Chlorphyll Content index
Chlo	Total chlorophyll in flag leaf
CIMMYT	Centro International de Mejoramiento de Maís y Trigo
DG	Dry gluten
DH	Days to heading
DMF	Total dry matter at flowering
DMM	Total dry matter at maturity
DMS-F	Dry matter of spikes at flowering
DMS-M	Dry matter of spikes at maturity
DMST-F	Dry matter of straw at flowering
DMST-M	Dry matter of the straw at maturity
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food And Agriculture Organization Statistics Division
FLA	Flag leaf area (cm)
FP	Filling period
GY	Grain yield
HI	Harvest index
ICARDA	International Center of Agricultural Research in Dry Areas
ITGC	Institut Technique des Grandes Cultures
MBB	Mohamed Ben Bachir
MNR	Marginal net return
MT	the mean temperature
NbrS m^{-2}	Number of spikes m^{-2}
NG	Nitrogen uptake by grain
NG/S	Number of grains per spike
NHI	Nitrogen harvest index
NL	Neck lenght
NM	Total nitrogen uptake at maturity
NSpk/S	Number of spikelet per spike
NST-M	Nitrogen uptake by straw at maturity
NUE	Nitrogen use efficiency

NUpE	Nitrogen uptake efficiency
NUtE	Nitrogen utilization efficiency
P%	Proteine
PH	Plant Heigh
RFFP	the total rainfall at flowering and filling period
RVP	the total rainfall at vegetative period,
SL	Spike lenght
SpW	Specific Weight
SW	Spike weight
TGW	Thousand grain weight
WG/S	weight of grains per spike,

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INTRODUCTION

One of the first domesticated food crops was wheat (*Triticum* spp.), which has been the main staple food of the major civilizations of Europe, West Asia, and North Africa (Curtis et *al*., 2002). Today, wheat is the most widespread crop, grown on wide land area than any other commercial crop and providing the most important food grain source for humans. According to FAO data in 2018, it is currently grown on about 214 million hectares worldwide that represents about 29% of the total cereal output and productivity of 734 Mt and provides nearly 19% of the food calories (FAO, 2020) and 20% of proteins for humans (Royo et *al*., 2017).

Durum wheat is one of the most important cereal crop and staple food in the Mediterranean basin, where is considered the largest durum wheat production area in the world, the most important import market and the largest consumer of durum wheat products, because of the dominant place which occupies the grain of durum wheat and its semolina in Mediterranean people's diet: couscous, bread, pasta, bourghul and frekeh. The total durum wheat production in Mediterranean Basin is ranging from 14–20 million t about 14-50 % of world durum wheat production (Ranieri, 2015; Tedone et *al*., 2017).

The main areas cultivated with durum wheat in Mediterranean are 1.6 million ha in Algeria (ITGC, 2019a), 1.5 million ha in Italy, and 0.5 to 0.8 million ha in Morocco, Tunisia, Turkey, Spain, Portugal, and Greece (Bonjean et *al*., 2016) with total production of 3.7 million t in Italy, 3.1 million t in Algeria (ITGC, 2019a), 1.3 million t in France, 2.1 million t in Turkey, 1.4 million ha in Morocco, 1.3 million ha in Tunisia, 0.8 million ha in Greece and Spain for each one. However, the countries within the Mediterranean basin do not meet their durum wheat demands and import over 5 million tons each year, primarily sourced from North America. (Ranieri, 2015; Tedone et *al*., 2017).

Algeria is among top durum wheat producer in Mediterranean, its part in total cereal area is 46% and total production is estimated on 52.46 %) (2018). The annual production varies significantly because of dependent to rain, it is ranging between 1,3 - 3.1 million t (Ranieri, 2015; ITGC, 2019a) and covers only 24% of the annual consumption which is around 202 kg / capita / year (ITGC, 2019a).

The weakness of cereal production in Algeria is mainly due to weakness and irregularity of grain yields, which does not exceed an average of 21 q/ha (ITGC, 2019a).

These weakness is mainly due to the effect of the dry climate that often occurs during the crop cycle (Insufficient and erratic rainfall, low winter temperatures, spring frosts, drought and late-season sirocco occurrence) (Benbelkacem, 1996; Mekhlouf et *al*., 2006), combined with the more recent effects of climate change (Cammarano et *al*., 2019), which are forcing farmers to adopt extensive cropping systems in rainfed farming areas (Bessaoud et *al*., 2019) with poor control of the agricultural technical itinerary (Di Mola et *al*., 2021). The main challenge under these climatic conditions is to reach the best grain yield with high quality by optimization of nitrogen (N) fertilization and the choice of variety (Carucci et *al*., 2020).

The nitrogen fertilization figure among the inputs of which the use strongly increased, because it constitutes, after water, one of improvement factors of grain yield and quality (Yadav et al., 2017; XU Hai-cheng et al., 2018). However, in the same time economic and environmental negative effect can be observed if this fertilization is not effectively managed (Foulkes et *al*., 2009; Gaju et *al*., 2011; Ladha et *al*., 2016; lopez-bellido et Lopez-bellido, 2006; Masclaux-daubresse et *al*., 2010; Tedone et *al*., 2017; Ziadi et *al*., 2007).

The management of nitrogen fertilization in the semi-arid zone is the most problematic in Algerian rainfed agriculture. The response to nitrogen in these conditions depends on several factors, including the initial richness of the soil in this element (Soltanpouret, 1989) and soil moisture (Karrou, 1996) or climate change (precipitation during the March–May period), agronomic practice (normal or conservative soil management), the quantity and number of fertilizer operations, and the type of fertilizer applied (Basso et *al*., 2009; Tedone et *al*., 2018). There for the difficulty is to manage the nitrogen while arriving to a right management program (Rate, source, timing, and placement of fertilizers). difficulty is result of the rapid mobility of nitrogen and its transformations according to the change of moisture and temperature of the soil (Karrou, 2001) and its various losses, namely volatilization, leaching, surface runoff and denitrification by the soil-plant system (Yadav et *al*., 2017).

According to Karrou (1996), in zones semi-arid areas characterized by a shortage of rainfall, the justification for nitrogen supply is not always apparent. Additionally, the substantial intra- and inter-annual fluctuations in rainfall make it challenging to reason out nitrogen fertilization. In instances of early rain, a high nitrogen supply can stimulate plant growth and increased tillering, leading to rapid soil water depletion. Consequently, this can result in lower grain yields if subsequent rainfall conditions are deficient during the grain-filling period.. Benchelali (2015), confirms these findings in the semi-arid zone of Sétif in Algeria during the winter season, characterized by high rainfall and low temperatures. The excessive application of nitrogen to durum wheat encourages the overproduction of herbaceous tillers and spikes/m2, resulting in the depletion of soil moisture. This situation exposes the grain-filling phase to water deficits.

In the event of water deficit occurs throughout the entire growing season, the uptake of nitrogen is reduced or may even cease, rendering the nitrogen supply a waste for the farmer. (karrou, 2001; Moll et *al.,* 1982). To remedy situation, it is necessary to reduce N fertilizers applied in these areas and to select varieties who value the nitrogen better or who have a better Nitrogen use efficiency.

According to Hirel et *al*., (2007) and Masclaux-Daubresse et *al*.,(2010), lowering N fertilizers applied and breeding plants with better nitrogen use efficiency (NUE) is one of the main goals of plant nutrition research to reduce damage due to nitrate leaching and water pollution, therefore preserve the environment and improve a sustainable and productive agriculture, while Kichey et *al*., (2007), report that lowering the amount of N fertilizers applied to the field without producing a N deficiency, will be the main challenge faced by breeders in selecting for cereal cultivars that absorb and/or metabolize N more efficiently.

As a concept, Nitrogen use efficiency NUE is the efficiency ratio of output (economic yield) to input (fertilizers). Moll et *al*., (1982), has been defined NUE as grain yield per unit of available N (soil + fertilizer N or as fertilizer N). They also suggested that NUE could be divided into two components: N uptake efficiency (NUpE, plant N per unit of either soil + fertilizer N or only fertilizer N) and N utilization efficiency (NUtE, grain yield per unit of N in the plant). NUE in plants is complex and depends on nitrogen availability in the soil and on how plants use nitrogen throughout their life span (Masclaux-daubresse et *al*., 2010).

According to Lopez-bellido and Lopez-bellido, (2006) work’s in the Mediterranean climate, the periodical soil water shortages have a considerable impact on fertilizer efficiency. Generally speaking, the efficiency of fertilizer N in Mediterranean climates is lower than that observed in temperate areas. Moreover the increased economic and environmental concerns have increased the need to manage N fertilizer use more judiciously.

Therefore, the management of nitrogen fertilization in the semi-arid zone, the focus should be for reducing excessive input of N fertilizers and breeding wheat cultivars which can use N more efficiently to maintain an acceptable yield and adequate grain protein contents, thus improving the economic efficiency of the crop and reducing negative agricultural impacts on air and water due to nitrate leaching and volatilization and at the same time preserving the environment, and improving a sustainable and productive agriculture (Zarei et *al*. 2017,; Moll et al., 1982; Hirel et *al*., 2007; Foulkes et *al*., 2009; Giuliani et *al*., 2011; Naser et *al*., 2020)

Furthermore, in semi-arid conditions the response of tall or short genotypes and old or modern ones to N fertilization is not well elucidated. From these premises, we hypothesized that the intraspecific variation is one of the keys to improving the NUE under semi-arid conditions. Consequently, the main objectives of this investigation were to:

- To fill the knowledge gap on NUE in durum wheat under semi-arid conditions in Algeria (2016-2018).
- To evaluate the effects of N rates on agronomic and economic aspects of the most widespread Algerian durum wheat genotypes determining the most efficient in terms of N use efficiency (NUE).
- To evaluate the effect of weather conditions (the total rainfall at vegetative period, the total rainfall at flowering and filling period and the mean temperature) on grain yield and NUE and theirs components and its effect on response to nitrogen fertilization under two contrast environments (Algeria and Italy) .

CHAPTER 1: LITERATURE REVIEW

1. DURUM WHEAT CROP

1. 1. IMPORTANCE OF DURUM WHEAT AND ITS CULINARY FORMS

Durum wheat is an important grain-crop particularly in Mediterranean; it is the main staple food and used to make various end-products because of its unique characteristics: hardiness (Hardest of all wheat classes), larger kernels, vitreous kernels, golden amber color and high protein content. All these characteristics give it several uses in food and became an essential element in the different dishes and eating habits in worldwide (Dimitrios, 2023).

The common uses are the pasta and bread, but there are other uses that differ depending on the eating habits of people around the world such as couscous, frekeh, bulgur, puffed cereals, hot cereal, desserts, and various types of bread.

According to (Boyacioglu, 2017), durum wheat has two main groups of consumers: European and American countries almost exclusively use durum wheat for pasta products, whereas in the Middle East and North Africa local bread making accounts for about half of durum wheat consumption, while the remaining half is used for pasta, couscous and various other uses. Furthermore, in the Mediterranean area and particularly in South Italy, durum wheat is used in the formulation of several types of bread.

Durum, is derived from a Latin word meaning “hard”, its hardiness, its kernel size, golden amber color and high protein content give it several uses in food and contributes, the most famous and common are couscous, flat bread, pasta, Frick but there is various kinds of traditional products which are varied between regions in Algeria (North, South, Est and West).

In Algeria, durum wheat with common wheat are the backbones of the Algerian food system, the most famous and common uses of durum wheat are couscous, flat bread, pasta, frekeh, but there are various kinds of traditional products which are varied between regions in Algeria (North, South, Est and West) and based on the raw material, it can consist of either intact or crushed grains, or semolina derived from grinding wheat..

- ✓ For the intact grain, the famous traditional dish is cherchem (grain cooked in water).
- ✓ For the crushed grain, the famous traditional dish is frekeh (parched immature wheat grain and cracked).

- ✓ For the semolina, there are many dishes: Flat bread (Kesra Or Khobz Eddar), Couscous, Pasta (Aich, Trida, And Rechta), Pastries (Zlabia, Ghrayef, Tamina, Ziraoui, Makrout, Braj, And Msaman). All these culinary forms require a high quality raw material, which the preferred ones are the protein content and the yellow color.

1.2. WORLD DURUM WHEAT PRODUCTION AND IMPORT

The annual global durum wheat production is estimated about 35–40 million t, harvested on about 18 million hectares (Royo et *al*., 2017; De Vita et Taranto, 2019), and it represents just 8–10% of the total area cultivated with wheat. It performs well in semiarid regions such as North Africa, Mediterranean Europe, the North American Great Plains and Middle East (Elias, 1995). Although it is considered a minor crop, it serves as the primary crop and staple food in the Mediterranean region, encompassing Southern Europe, the Middle East, and North Africa.

The most producers are European Union (Italy, Spain, France and Greece), Canada, Mexico, Kazakhstan, Turkey, USA, and North Africa (Algeria, Morocco and Tunisia).

In Mediterranean, Italy is the major producer of durum wheat with almost 4 million t in average. Turkey and France are the followers with average of 2.7 and 1.7 million t, respectively. Generally, smaller productions are characterizing Morocco, Algeria, Tunisia, mainly due to the effect of the dry climate that often occurs during the crop cycle (Ranieri, 2015).

Table 1. Estimated and forecasted worldwide durum wheat productions for 2014/15 and 2015/16 seasons (Ranieri, 2015).

	2014/2015 Estimated	2015/2016 Predict		2014/2015 Estimated	2015/2016 Predict
World total	32.6	36.1	Argentina	0.3	0.3
EU	7.1	7.5	Syria	0.8	1.4
France	1.5	1.8	Turkey	2.1	2.4
Greece	0.8	0.7	India	1.3	1.2
Italy	3.7	3.9	Algeria	1.3	2.5
Spain	0.8	0.9	Libya	0.1	0.1
Kazakhstan	2	2.1	Morocco	1.4	2.3
Canada	5.2	4.8	Tunisia	1.3	1.3
Mexico	2.3	2.3	Australia	0.5	0.5
USA	1.4	2.1	Others	5.7	5.5

EU countries and Algeria are among the top importers of durum wheat. In the 2015/2016 season, the EU imported 2.4 million tons of durum wheat, while Algeria imported 1.7 million tons during the same period. Other significant importers of durum wheat include Morocco, Tunisia, the USA, Venezuela, and Japan.

The leading countries in global durum wheat export are Canada and Mexico. Canada alone operates more than half of the global durum wheat export, which was 4.3 million tons in 2015/2016. Mexico has shown a significant success and reached 1.4 million tons in 2015/2016 season. At the third rank, there is EU countries. Their total exports recorded are 1 million tons in 2013/2014. USA, Australia and Turkey are following these three rivals (FAOSTAT, 2020).

1.3. PRODUCTION, CONSUMPTION AND IMPORT OF DURUM WHEAT IN ALGERIA

Algeria is the largest country in Africa covering 238 million hectares, with a total agricultural area of 43.43 million ha. Each year, an average of 3 million hectares land remains fallow, leaving a useful agricultural area of 8.49 million hectares. (ITGC, 2019a).

Cereals occupy around 2.9 million ha (average 2000-2012), or almost 35% of arable land, but with significant differences: 14% in 2000, 42% in 2009, due to the practice of fallow (Rastoin and Benabderrazik, 2014). In 2017-2018, cereals are grown on 3, 44 million ha, that more than 40% of UAA, which 1, 6 million ha durum wheat (46, 41%), 1,28 million ha barley (37,28%), 480 miles ha bread wheat (13,95%) and 81 miles ha oats (2,35%) (ITGC, 2019a). Their production is rainfed (less than 3% irrigated) and mainly located in humid and sub-humid areas, in the northern part of the country. Since the early 1970s cereal production was increased through the introduction of new varieties derived from natural populations or selections from within these populations (Benbelkacem, 2014).

The total cereal production obtained in 2017-2018 was 6 million t, which 3,16 million t of durum wheat (52.66 %), 1,95 million t of barley (32.5%), 0,79 million t of bread wheat (13.16%) and 0,117 million t of oats (1,95%) (ITGC, 2019a). Cereals in Algeria are mainly used for animal feed (61%) and human consumption (24%), while wheat occupies a very important place in the spatial structure of agricultural activity. It covers around 60% of the total cereal area.

Wheat production in Algeria has historically exhibited significant irregularities. However, the past decade (2008-2018) has shown an upward trend. Over the past 10 years, there has been an increase of 2,87 million t between a disastrous year (1,11 million t in 2008) and a year of abundance (3,98 million t in 2018) (FAOSTAT, 2020) (Figure 1).

Wheat production is divided between durum wheat (80% in 2018) and bread wheat (20%).

Durum wheat continues to maintain its status as the primary cereal in Algeria. It stands as the foremost and economically significant crop, constituting 80% of total wheat production, 52.66% of the overall cereal production, and covering 46% of the total cereal cultivation area, cultivated across 1.6 million hectares. Its average production ranges between 1.3 and 3.1 million tons ((ITGC, 2019a).

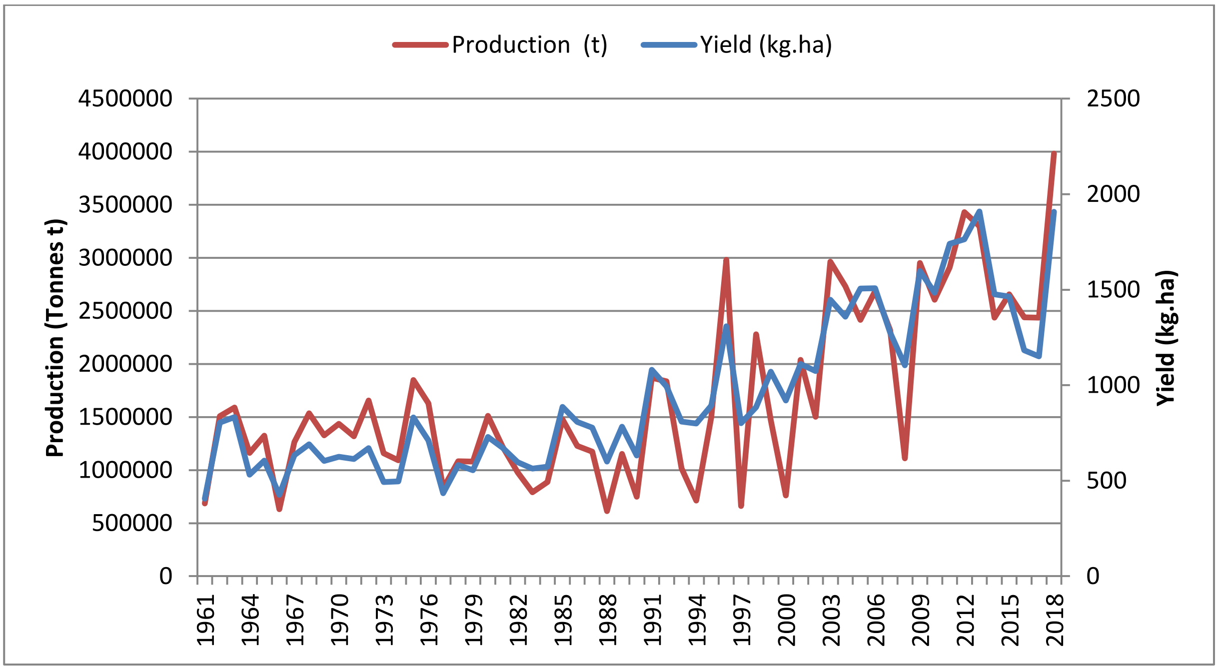


Figure 1. Wheat production, Algeria, 1961 – 2018 (FAOSTAT, 2020)

CNIS statistics (2017), show that the local production provides only 48 kg / capita / year, or 24%, for a need of 202 kg / capita / year in durum wheat, and 11 kg / capita / year, or 21 %, for a need of 52 kg / capita / year in common wheat, which gives a coverage rate by local production only 29% for the 2 wheat species (that 84 kg / capita / year for a need of 293 kg / capita / year) (ITGC, 2019a). The objective is therefore to fill a deficit estimated at 70% of the national consumption. This situation leads Algeria to import large quantities of wheat (The deficit concerns much more common wheat than durum wheat).

Before delving into Algerian wheat imports, it's important to note that during the Roman occupation era, North Africa supplied significant quantities of grains to Rome, the capital of the empire. These grains were collected as taxes from local communities. This historical role led to North Africa being referred to as "Rome’s granary." (Benbelkacem, 2014), If we revisit the 18th century (1710 to 1830), known as "the century of wheat," Algeria stood as the primary exporter of North African wheat to Marseille and Europe. During this time, France emerged as Algeria's primary customer for wheat. Algeria maintained its status as the principal supplier of North African wheat to France until the conclusion of the century and throughout the colonial period from 1830 to 1962. (glycines, 2014),

Algeria is the third importing country of wheat in the world after Indonesia (10.45 Mt), Egypt (10,16 MT) with 8 Mt in 2017. Then follow Italy (7.43 MT), Bangladesh (6.86 MT), Spain (6.18 MT) (FAOSTAT, 2020). By species, Algeria in 2018 imported 1.48 million tonnes of durum wheat, while common wheat import reached 6.5 million tonnes. Therefore common wheat leads these imports with a rate of 81%, followed by durum wheat with 18,5%. The main exporters of durum wheat to Algeria are Canada and Mexico while France and Germany serve as the main suppliers of soft wheat (Hales and Torry, 2022).

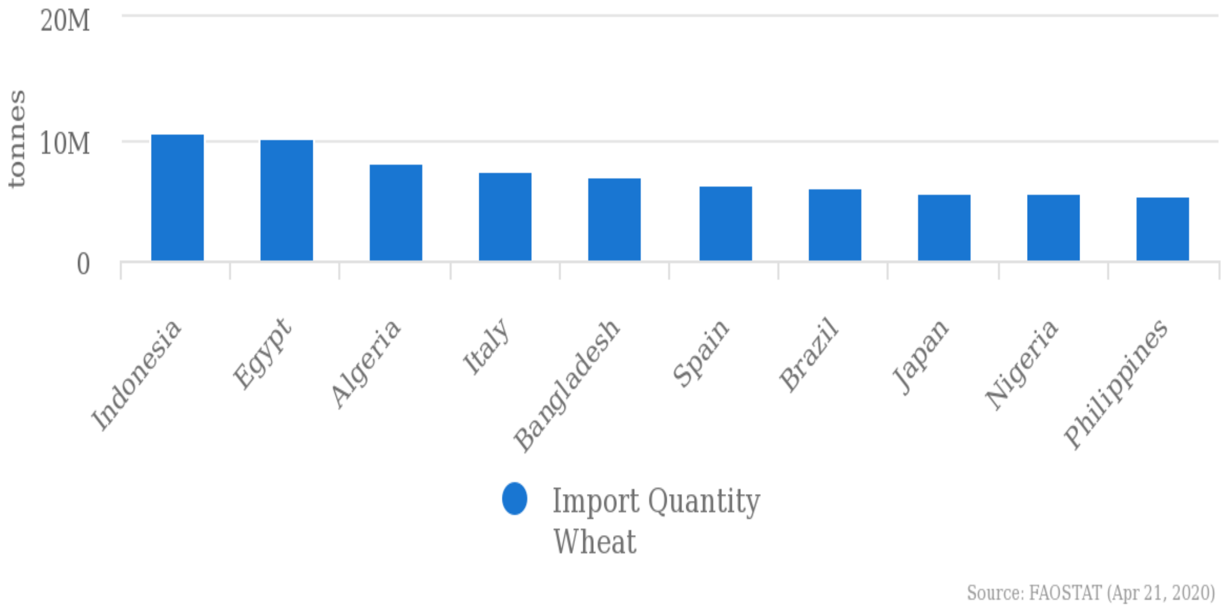


Figure 2. Top 10 country importers, import quantity of wheat (FAOSTAT, 2020)

1.4. POTENTIAL DURUM WHEAT PRODUCTION AREAS IN ALGERIA

It falls within the (Smadhi and Zella, 2009). According to (Benbelkacem et *al*., 1995; Meziani, 2002), cereal crop is practiced in four distinct areas:

- The coastal, sub-coastal plains and the northern highlands with 1.2 million hectares, which represent an area with high potential and an average yield ranging between 10 to 15 q / ha.
- The south of the highlands is an agro-pastoral area where cereal farming associated with sheep farming is practiced on 1.8 million hectares with yields range from 5 to 6 q / ha
- The steppe zone where the cereals crop is practiced irregularly, on 0.3 to 0.8 million hectares where barley is the dominant species.
- The Saharan zone with 45,000 ha is under irrigation and 10,000 ha are under pivot.

1.5. DIFFERENT VARIETIES OF DURUM WHEAT CULTIVATED IN ALGERIA

Variety is a prompt and cost-effective method to significantly increase yields (Nouar et *al.*, 2010). According to Hazmoune (2000), the varieties adopted in Algeria belong to two types of germplasm.

The local germplasm, consists of varieties selected from local populations. These varieties are characterized by a low production potential. However, they exhibit more consistency in terms of grain yield and display greater tolerance to abiotic stresses such as Hedba3, MBB, O.Zenati368 and Bidi17.

The exotic germplasm comprises recently selected varieties known for their high production potential. These varieties originate from international agricultural research institutions such as CIMMYT and ICARDA, exemplified by strains like Waha, Vitron, and GTA durum.

According to Douici-khalfi et *al.*, (2019), there are a total of 60 varieties reserved for production and marketing, however only 17 varieties are reserved to produce the seeds with 6 varieties which alone occupy 84% of the area of the durum wheat program, including Vitron with 27% , Bouseelam with 19%, Simeto with 14%, Chen'S with 9%, Waha with 8% and GTAdur with 7%.

In recent years, various varieties have been progressively introduced into production, considering the specific agro-climatic conditions of each region. For instance, Megress, Ain Lehma, and Targui are increasingly cultivated and gaining popularity in the wilayas of Sétif, Constantine, and Blida, respectively. (Figure 3).

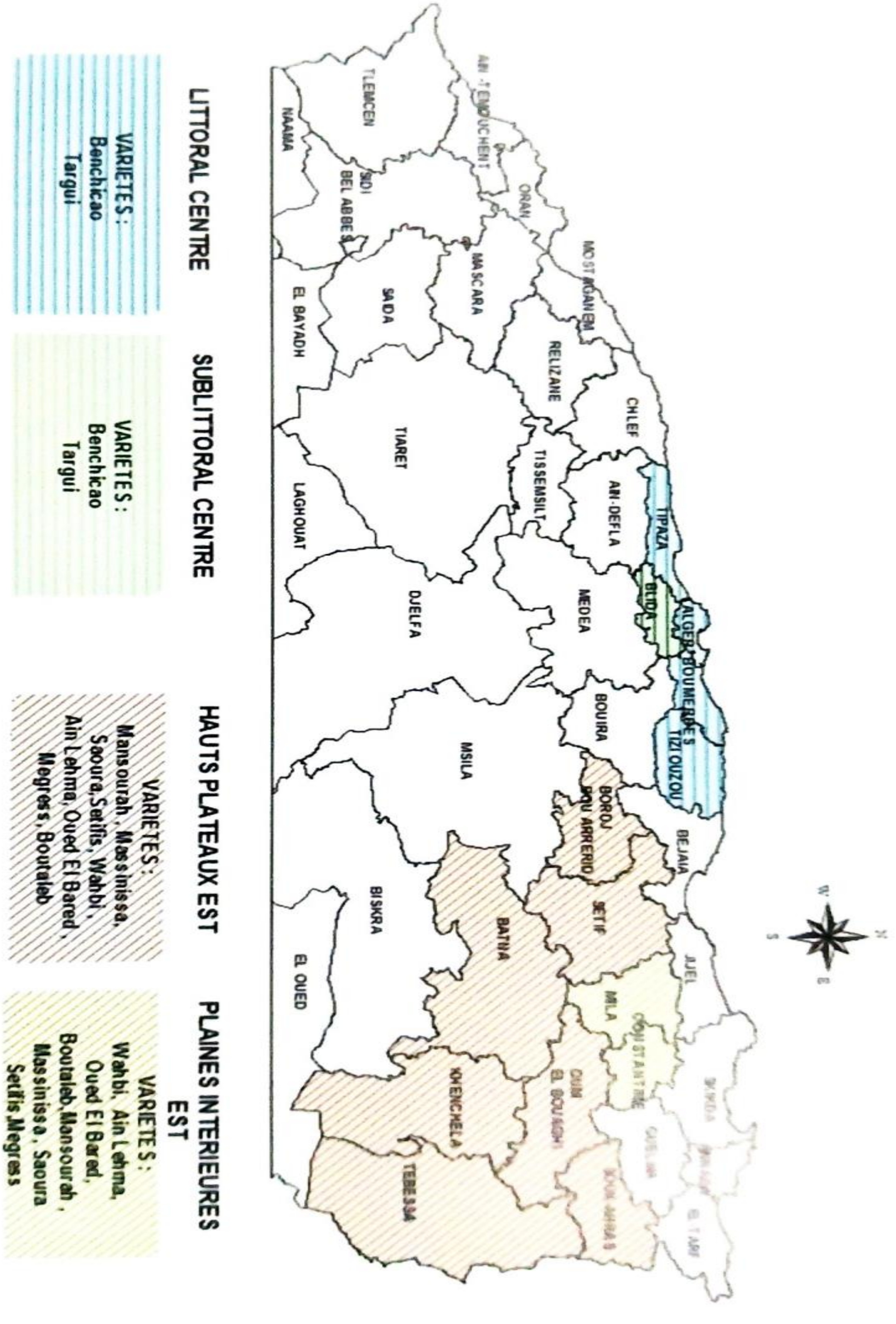


Figure 3 . Adaptation areas of modern durum wheat varieties in Algeria.(ITGC, 2019a)

1.6. DURUM WHEAT YIELD IN ALGERIA

Cereal yields depend on characteristics specific to each cultivar or its genetic patrimony, which the expression depends on environmental factors (Merabet and Boutiba, 2005). According the statistic of 2017-2018, the average yield, all cereals combined, was 19.44 q / ha, with 21.27 q / ha for durum wheat, 17.67 q / ha for the common wheat, 17.98 q / ha for barley and 15.23 q / ha for oats (ITGC, 2019a).

In Algeria, the wheat yields are low and mostly irregular (Kellou, 2008; Hamadache, 2013). Compared to the world average which is 29 q/ha for 2014, the yield of Algerian wheat is only for the best years 50% the world average, they are on average of 14,19 q/ha (2000-2018). But they showed a tendency to increase, Thus the average was 6,28 q/ha (1961-1990), it reached to 9,26 q/ha(1990-2000) and to 14,19q/ha (2000-2018) (FAOSTAT, 2020).

This increase is due to adoption of new varieties with high potential production and the use of new production techniques (row sowing and chemical weed control in particular). (Hamadache, 2013), and also the local production of durum wheat showed a strong increase following the premium per quintal which is added (Belaid, 2021).

Table 2. The wheat yields in Algeria from 1961 to 2018 (FAOSTAT, 2020).

Mean	1961-1990	1990-2000	2000-2018
Yield Kg/ha	638,723333	926,736364	1419,81053
production tonnes	1197733,73	1440099,36	2509515,53

1.7. DURUM WHEAT QUALITY IN ALGERIA

According to the international standard ISO 8402, quality is defined as the set of properties and characteristics of a product which gives it the ability to satisfy the needs expressed by consumers or customers (Feillet, 2000). The quality of durum wheat may be evaluated by more than one point of view: agronomical quality that influences potentiality and stability of grain yield; milling quality that influences semolina yield, ash content, humidity, and impurity of grains; technological quality that influences content of protein and gluten quantity and quality; hygienic and sanitary quality that are related to some phytopathological microorganisms or their secondary metabolites. Recently, the consumer is also oriented toward other meanings of quality based on environmental and ethic friendly production (Fagnano et *al*., 2012).

The technological quality of wheat covers many criteria which depend on the use of the product (semolina, pasta, couscous) (Jeuffroy, 2006; PSDR, 2006). According to (Loue, 1970), two parameters revealing the potential of durum wheat grain quality are:

- The semolina value or semolina yield which is linked to the vitreous structure of the grain.
- The qualitative value of semolina mainly depends on: total protein content and wet gluten, the content of yellow pigments which cause the coloring of the pasta.

According to (Bousquet, 2006; Cauwel et *al*., 2000; Loue, 1970; PSDR, 2006), the speckle, the mitadinage and the protein content are the three essential criteria for assessing the quality of durum wheat.

In Algeria, durum wheat quality is characterized by poor quality: presence of impurities which can damage the processors' industrial tool, presence of weed seeds and high mitadinage rate (Belaid, 2021).

1.8. DURUM WHEAT PRODUCTION CONSTRAINTS IN ALGERIA

The constraints in wheat production in Algeria encompass environmental, technical, and human factors simultaneously. (Rastoin and Benabderrazik, 2014). When discussing environmental constraints, wheat production is limited by various climatic, edaphic and biotic factors.

According to Benbelkacem et *al*., (1995) andBenbelkacem (1996) , in Algeria, weather stresses from drought and cold are almost always combined together, often occurring in combination with other stresses like low winter temperatures (frosts in winter and early spring) and heat during the final period of grain filling which is the an important stress factor in highlands, with nutritional stresses, lack of macro- and micronutrients) and with biotic stresses (diseases and insect pests).

For the technical, it's about, the general tendency of farmers to minimize the risk by simplifying cultivation techniques such as: reduction of cultivation methods, elimination of rolling after sowing, chemical fertilization and weeding which are eliminated in most cereal farms (Kellou, 2008), For human constraints, it's about the low organization and formation of producers, and also "regionalization" of production conditions and therefore contrasting harvest levels from East to West in the same year (Rastoin and Benabderrazik, 2014).

2. NITROGEN USE EFFICIENCY NUE IN DURUM WHEAT

2.1. MANAGEMENT OF NITROGEN FERTILIZATION OF DURUM WHEAT IN ALGERIA

The world agricultural use of nitrogen is estimated at 113 million tonnes in 2020 (FAOSTAT, 2023). In Algeria the quantities is estimated to 70,2 tonnes in 2020, and they are greater in durum wheat.

In Algeria, the total nitrogen level uses in rainfed wheat varies between 50 and 100 units/ha for yields of 20 at 40 q/ha. It is to be reasoned according to the rainfall, the yield objective expected, soil organic matter and mineral nitrogen content at the time of application (Hamadache, 2013).

According to (ITGC, 2019b), the quantities are be reasoned according to the rainfall, and the yield objective expected and the species (Table 3).

Table 3 . Nitrogen needs of durum wheat (U/ha)(ITGC, 2019 b)

		rainfall area with		
		600mm	400mm	Between 300 and 400mm
The species	Needs to produce a quintal of grain	Yield objective of 40 to 50 (q/ha)	Yield objective of 20 to 30 (q/ha)	Yield objective of 10 to 15 (q/ha)
Durum wheat	3,5 U	140-175	70-105	not concerned
Common wheat	3 U	120-150	60-90	not concerned
Barely	2,4U	96-120	48-72	24-36

The most N fertilizers used are ammonium sulphate at 21% and urea 46% (Hamadache, 2013).

2.2. IMPORTANCE OF NITROGEN FOR PLANT GROWTH AND DEVELOPMENT

Nitrogen plays a fundamental role in the constitution of plant matter (Schvartz et *al*., 2005), plants in general contain 3-5% N in their shoot tissue biomass, they absorb N from the soil in the form of NO3- and NH4+ ions. Most N uptake is in the form of NO3-, which moves from the soil solution into the plant root cell with absorbed water. NO3- is then either stored in the vacuole or reduced in the cytosol and plastids eventually to NH4+ through the activity of nitrate and nitrite reductase (NR, NiR) respectively (Zhang et *al*., 2017).

N improves the functioning of the whole plant and more particularly that of photosynthesis (Gate, 1995). It has a central role in plant biochemistry as an essential constituent of cytoplasmic proteins, nucleic acids, chlorophyll, cell walls and a vast array of other cell components. N improves root systems, which has special significance in absorption of water and nutrients (Hay and Walker, 1989; Fageria and Filho, 2001).

N content is indirectly a determinant of the rate of photosynthesis, dry matter accumulation, and economic yield. Because of these multiple roles of N, plant growth and yield of grain cereals are often affected by levels of N supply (Anbessa and Juskiw, 2012).

The main effect of an increased N supply on growth is through increased canopy green area (rather than through increased net assimilation rate or leaf net photosynthesis) from both higher tiller survival (Hirel et *al*., 2007), it is possible to diagnose nutritional disorders by visual symptoms deficient plants show stunted growth, yellow leaves, reduced tillering in cereals, reduced pods in legumes, and consequently, yield reductions in both cereals and legumes (Yadav et *al*., 2017). Consequently, a deficiency in the supply of nitrogen has a profound influence upon crop growth and can lead to a total loss of grain yield in extreme cases (Hay and Walker, 1989).

In general, nitrogen deficiency decreases grain yield and quality of grain. Therefore, there needs to be sufficient N supply to maintain proper biological functions and ultimately to obtain good yield from crop plants (Anbessa and Juskiw, 2012).

2.3. NITROGEN NEEDS OF DURUM WHEAT

The needs of durum wheat are generally greater than those of common wheat. In general, to supply nitrogen fertilization at the right dose and at the right time, it is necessary to know well the evolution of nitrogen needs of wheat, in order to adjust or offset as best as possible the intakes with the needs of the crop. This translates into better efficiency in the use of nitrogen to limit the risk of lodging, to optimize the yield and to contribute to high protein content of the grain (Bahloul, 1985).

The daily nitrogen needs of a crop are linked to its ability to grow, the nitrogen uptake by plants is therefore largely determined by growth (Lemaire et *al.*, 1997), The nitrogen nutrition of durum wheat begins from the herbaceous tillering with higher needs from the spike-1 cm stage until flowering stage (Gate, 1995). (Morel, 2007), confirmed that the needs for durum wheat from emergence at the 1 cm spike stage are low, not exceeding 10 to 15% of the total needs; while 70 to 80% of the N needs are absorbed between steam elongation and flowering. Moreover, during the grain filling stage, the plant absorbs relatively low nitrogen quantities, which is 20% of the total quantity present at harvest. The mineralization of organic nitrogen in the soil is sufficient to meet this low need(Gate, 1995).

The current method for forecasting wheat nitrogen needs is based on fixation of yield objective: Needs (kg N) = b*(Expected yield, in q/ha), where the coefficient b represents the quantity of nitrogen necessary to produce 1 quintal of grains.

For durum wheat with 14% protein content, the coefficient b is 3.5 kg N / q of grains (Comifer, 2011; Jeuffroy et *al*., 2013). The yield objective can be set as soon as sowing according to the potential of the variety and pedoclimatic conditions, and it is possible be revised during the cycle, especially at the end of winter (Gate, 1995).

2.4. EFFECT OF NITROGEN FERTILIZATION ON YIELD AND QUALITY OF DURUM WHEAT

The N fertilization has been an important contributor for the tripling of global cereal production during the past five decades (Anbessa and Juskiw, 2012). The effect of nitrogen is well known to increase the yield and quality of wheat grain and its deficit causes their decrease.

Many studies have clearly demonstrated the positive and significant effect of N in increasing wheat yields (Lopez-Bellido et *al*., 2004; Garrido-lestache et *al*., 2005; Jeuffroy, 2006; Abdellaoui and Mariche, 2008; Djennadi-Ait Abdallah and Rafoufi, 2008; Ercoli et *al*., 2008; Hategekimana et *al*., 2012)

Wheat is very sensitive to nitrogen deficiency and is highly reactive to the element. One of the most obvious responses to nitrogen deficiency is chlorosis, as a result of the lack of chlorophyll synthesis and reduced cell size and proliferation, leading to a stunted, reduced leaf surface and a yellowish (chlorotic) appearance of the crop and cause poor plant growth and reduced yield (Tedone et *al*., 2018).

Nitrogen promotes digestion and increases vegetative growth, the number of spikes per plant and the dimension of the spike, the weight of the kernels and the protein content. Excess nitrogen may favor lodging, particularly in tall grain varieties, and retard the cycle with stress on grain filling if the season course is dry. The culture is also more susceptible to rust and septoria attacks (Tedone et *al*., 2018).

Numerous studies have shown that the N uptake and remobilized quantities improve more by the supply of nitrogen (Barbottin, 2004; Ercoli et *al*., 2013; Jeuffroy, 2006; Kichey et *al*., 2007; Pask et *al*., 2012).

Gate (1995); Habib et *al*., 1997; Barbottin, 2004; Jeuffroy, 2006; Kichey et *al*., 2007), note that the major part of N in the grain comes from the remobilization of N uptake before flowering. Furthermore, Bogard (2011) and Le Gouis (2012) note that this fraction varies from 40 to 90%. In addition, N uptake in post-flowering, although relatively low, is a significant source of nitrogen during the filling phase (Le Gouis , 2012). (Jeuffroy and Oury, 2012), also reported that the nitrogen absorbed during the grain filling period contributes directly to the protein enrichment of the grains.

From a crop production standpoint, N is generally the most limiting plant nutrient and N availability is routinely supplemented through applications of fertilizer (Huggins and Pan, 2003), however in cereals; less than half of the applied N is recovered in the grain (Raun and Johnson 1999). This fertilizer inefficiency may contribute to environmental degradation, therefore Improving nitrogen use efficiency (NUE) of crop plants is thus of key importance (Masclaux-Daubresse et *al*., 2010).

2.5. NITROGEN USE EFFICIENCY NUE AND ITS COMPONENTS: DEFINITION AND CONCEPTS

2.5.1. NITROGEN USE EFFICIENCY NUE

The term efficiency is often used as a synonym for effectiveness. However, their meaning is different: effectiveness corresponds to the ability to achieve a specific objective, while efficiency expresses the relationship between a result and the means used to achieve it (ISO 9241, 1998) (Bevan et *al*., 2015). As an illustration, nitrogen fertilization will be qualified as effective if it permit to achieve an objective yield (regardless of the quantity of nitrogen applied) while fertilization nitrogen will be qualified as efficient if it permit to maximize the yield per unit of fertilizer applied, or minimize the amount of nitrogen to be used per unit yield.

The concept of nitrogen use efficiency (NUE) has been widely used to characterize plant behavior regarding different levels of nitrogen (N) availability (Cormier et *al*., 2016). Many definitions of NUE exist in the literature, but that of Moll et *al*. (1982) is one of the most complete, as it does not only refer to the nitrogen of manure and fertilizers (Tedone et *al*., 2018).

Nitrogen use efficiency (NUE) has been defined by Moll et *al*. (1982) as grain production per unit of N available in the soil.

Nitrogen use efficiency NUE = Gw (kg ha-1) / Ns (kg ha-1) ……..Equation 1

which *Gw* is grain weight and Ns is N supply expressed in the same units. There are two primary components of N use efficiency: (1) the efficiency of absorption (uptake), and (2) the efficiency with which the N absorbed is utilized to produce grain. These are expressed as follows:

N uptake efficiency NUpE = Nt/Ns…….. Equation 2

N utilization efficiency NUtE = Gw/Nt ………Equation 3

Where Nt is total N in the plant at maturity, the product of these two components results in NUE. It follows that:

Gw/Ns = (Nt/Ns)(Gw/Nt), NUE= NUpE * NUtE ………Equation 4

The authors noted that plant available N was difficult to measure; it has been defined in different ways: Limon-Ortega et *al*., (2000), estimated N supply as the sum of (i) N applied as fertilizer, and (ii) total N uptake (Nt) in control (0 N applied) plots.

Huggins and Pan (2003), estimated N supply as the sum of all sources of potentially available N such as N fertilizer (Nf), residual inorganic soil N prior to crop N uptake (Nr), soil mineralized N (Nm), N fixed in clay minerals (Nx), and depositional N (Nd) from atmospheric, irrigation and run-on N. To assess retention of soil N supply, available soil N (Nav) is defined as N supply minus soil N losses due to immobilized N (Nim), N leached (Nl), N eroded (Ner), gaseous N losses (Ngl), and N chemically fixed (Ncf)

Giambalvo et *al*., (2004, 2010), estimated N supply as the amount of applied N plus aboveground plant N plus residual postharvest N in the soil, both determined from control plots (no applied N).

Cormier et *al*., (2016), report that Bingham et *al*. (2012) compared different methods to estimate available N. The first one was independent of genotype and used only residual soil N after winter and applied N fertilizer. The two others were dependent on the genotype and required a control without N fertilization (N0). Available N for the fertilized treatment (NT) was then estimated either (i) by adding the above-ground plant N at harvest for N0 to the applied N fertilizer or (ii) by adding soil N at harvest to (i). Bingham et al. (2012) showed that genotype rankings were very similar between the three methods, and thus, the simplest method can be used.

An alternative approach to evaluating NUE is to compare performance at low and high N inputs. The rationale is that efficiency traits, particularly for capture, may only be expressed under low N conditions. Moreover, as modern selection is mostly performed at high inputs, selection pressure may have led to the loss of these traits for efficiency at low availability. In addition, the trait of responsiveness to N fertilizer is useful agronomically, indicating a variety able to exploit the added N efficiently. (Hawkesford, 2017)

NUE in cereals is generally poor, where it is estimated 33% of the total of N-fertilizers applied is actually harvested in the grain (Raun and Johnson, 1999) and it generally decreases with increasing N rat (Dobermann, 2005).

Many studies have reported losses of fertilizer N in cereal production from 20 to 50% (Raun and Johnson, 1999). These losses have been attributed to the combined effects of denitrification, volatilization, and/or leaching (Yadav et *al*., 2017).

Enhanced NUE may result from increased efficiency of recovery of soil available N (uptake efficiency) and higher efficiency of utilization of the N taken up for grain formation (utilization efficiency) (Moll et *al*. 1982).

Le Gouis et *al*., (2000), reported that NUpE explained more the genetic variation of NUE under low N than at high N conditions. However, other research found that NUtE explained more of the variation in grain yield than NUpE under low and high N condition (Gaju et *al*., 2011). Therefore, understanding the mechanisms regulating these two processes is essential for the improvement of NUE in crop plants.

2.5.2. NITROGEN UPTAKE EFFICIENCY NUPE

Nitrogen capture would appear to be the key underpinning trait aligned to efficiency. NUpE is defined as the amount of N taken up by the crop as a function of the N available (Hawkesford, 2017). N-uptake efficiency NUpE= Nt/Ns is an index of total N in the plant at maturity to N supply. To estimate the total amount of N in the plant, usually only the aerial parts are sampled. Not taking into account N in the roots would increase NUtE and decrease NUpE (Cormier et *al.*, 2016).

Nitrogen uptake efficiency reflects the efficiency of the crop in obtaining N from the soil available nitrogen and the nitrogen supplied fertilizer. Increased NUpE has been proposed as a strategy to increase NUE by Raun and Johnson (1999). Additionally, Moll et *al.*, (1982), has been shown that NUpE is directly correlated to NUE.

The total N uptake from soil is affected by the developmental stage of the plant, the maximum occurred in periods of vegetative growth, while that declined during plant maturation and grain filling phase (Gate, 1995). Feil (1992), indicated that cultivars producing large amounts of biomass seem to have more efficient nutrient uptake, which could decrease the total NUE of modern cultivars.

Delogu et *al.*, (1998) and Le Gouis et *al.*, (2000), reported that, the total N uptake rates can be affected by genetic factors and they have shown significant differences between varieties for N-uptake in wheat. Moreover (Hawkesford, 2017), reported that the efficiencies of N uptake will affected by environment factors such as : cropping systems and strategies for N application in terms of timing, splitting of applications, and forms of N used.

2.5.3. NITROGEN UTILIZATION EFFICIENCY NUTE

Nitrogen utilization efficiency (NUtE) is a parameter expressing the ability of the plant to translate the N uptaken up to economic yield (grains) (Delogu et *al.*, 1998). It is governed by a complex network of nitrogen cycling enzymes and processes (Masclaux-Daubresse et *al.*, 2010).

N taken up by wheat during its vegetative stage is used for the construction of the canopy, including its structural elements and functional components, particularly the photosynthetic system. In grain filling, the potential yield will be determine after senescence and remobilization of N accumulated in the vegetative canopy (Hawkesford, 2017). Therefore, NUtE concerns yield determining processes, including the N necessary for canopy construction, the development and maintenance of photosynthetic activities, grain filling through carbohydrate and N remobilization.

The quantity of N remobilized into grains mainly depends on nitrogen remobilization efficiency and the amount of stored N during post-anthesis in the plant and it can be influenced by genotypic and environmental variables (Hawkesford, 2017)

2.5.4. THE N HARVEST INDEX (NHI)

NHI is the ratio of N present in grain to total plant N content or total N uptake (NHI =Ng/Nt). It is the fraction of N recovered in the final grain fraction as a function of the total N taken up (Dawson et *al*., 2008; Hawkesford, 2017). Using the harvest index (HI) and nitrogen harvest index (NHI), one may ascertain how crucial nutrients are distributed among plant tissues during the reproductive growth of grain. NHI is an important parameter in cereals. NHI reflects the grain protein content (Hirel et *al*., 2007) and N translocation efficiency (Dawson et *al*., 2008).

2.6. IMPROVING NITROGEN USE EFFICIENCY

Improving NUE of crop plants is important for two reasons: Firstly, reduce the major expenses of crops production. Secondly, reduce the environmental damage caused by the use of nitrogen fertilizers.

Generally, NUE in plants is influenced by a wide range of variables. The weather, soil type, previous crops, fertilizer type, timing, plants and varieties are the most important factors among these. Multiple impacts might be difficult to separate when combined, and this can result in a significant difference in the plant's NUE.

To increase crop NUE, two complementary strategies can be employed: improvement through crop management or genetic enhancement of nitrogen use efficiency.

2.6.1. MANAGEMENT STRATEGIES TO INCREASE N-USE EFFICIENCY

Agronomic or management strategies to increase N-use efficiency may be achieved through different ways:

►**Optimizing N inputs:** One of the main causes of low NUE is the limited synchronization between N soil availability and crop demand. As a result, numerous agronomic strategies are being used to increase NUE in grain crops, including:

- Consideration of the growing environment and getting the right dose at the right time (Raun and Johnson, 1999).
- Taking into account sources of N (soil, previous crops, animal manures) Raun and Johnson (1999).
- The use of decision support tools that support integrative N management strategies (Huggins and Pan, 2003; Ladha et *al*., 2005; Anbessa and Juskiw, 2012).

►**Optimizing soil management practices:** Major effects on N use have frequently been reported for crop rotation, tillage regime, genotype, water management (Raun and Johnson, 1999; Huggins and Pan, 2003). Among the agronomic strategies used:

- Using cover crops to keep soil N and organic matter in place;
- Increased use of crop rotations (both shallow and deep rooted), avoiding wheat-fallow or wheat-wheat situations, and placing wheat after legumes;
- Use of modern farming methods, such as conservation tillage, to manage weeds, soil moisture, and erosion;
- Determining the ideal rate, distance, and depth for sowing in order to use the most of soil water and fertilizers.

►**Enhanced Efficiency Fertilizers:** Enhanced efficiency fertilizers (EEFs) have been developed as a way to minimize N losses since conventional fertilizers are prone to N losses to the environment. These EEFs include slow-and controlled-release fertilizers (i.e., fertilizers characterized by slow hydrolysis of water soluble compounds or those that have controlled water solubility due to semi-permeable coatings or other chemicals) and stabilized nitrogen fertilizers (i.e., fertilizers to which stabilizers like nitrification and/or urease inhibitors have been added) (Anbessa and Juskiw, 2012).

2.6.2. GENETIC ENHANCEMENT OF NITROGEN USE EFFICIENCY

Genetic improvement in NUE may be achieved through changes in one or more of the plant’s morpho-physiological traits, which directly or indirectly contribute to its superior ability to take up and/or utilize available N (Anbessa and Juskiw, 2012).

Several morpho-physiological traits affect the level of NUE improvement, the most studied in wheat are: the specific root traits (weight, length and density), enzymes of nitrate assimilation, N distribution, photosynthesis, senescence, high biomass yield and nitrogen harvest index NHI (Cormier et *al*., 2016; Zhang et *al*., 2017; Alhabbar et *al*., 2018).

According to Anbessa and Juskiw (2012) , in barley, there is a direct correlation between biomass and NUE. High biomass results from the plant's internal efficiency to use the N taken-up to produce dry matter. High above-ground biomass is also frequently linked to a strong root system and more N uptake. Therefore, the two most effective strategies for increasing NUE, would be to have better root systems and high above-ground biomass yields while maintaining harvest index.

Furthermore there is a need to better understand N use in wheat, particularly the plant‘s capacity for mining N from the soil and its efficient use once within the plant.

The use of genetic variability for Nitrogen Use Efficiency to developed superior cultivars through crossing and pyramiding of NUE genes from different sources could enhance NUE. (Anbessa and Juskiw, 2012). Candidate traits to change may exist at the canopy, leaf, or biochemical level, and can be identified through detailed physiological and modelling studies. Further genetic studies applying molecular marker mapping approaches using appropriate segregating populations can identify Quantitative Trait Loci (QTL) for complex traits such as NUE and underlying traits (Hirel et *al*., 2007).

CHAPTER 2: MATERIAL AND METHODS

1. SITE DESCRIPTION AND CROP MANAGEMENT

This thesis is based on data from four growth experiments, three in Algeria (2016-2017-2018) at the experimental Algerian Field Crop Institute in Sétif-Algéria (ITGC) and one in Italy 2019 at the Cereal Research Centre (CREA-CI) in Foggia,Italy (Figure 4). The same experimental design and treatments were applied in all experiments.

The geographical coordinates of the sites are reported in Table 4. In Algeria, the climate of Sétif is typically subject to semi-arid conditions with low mean long-term rainfall of 359.3 mm. However in Italy, the climate of Foggia is typically subject to Mediterranean conditions with mean long-term rainfall of 479 mm. Figure 5 and 6 shows the monthly air temperatures and precipitation during the four growing seasons.

The soil chemical and physical properties are reported in Table 3. The previous crop of trials in Algeria was fallow in the first and second year and wheat in the last year and fallow in Italy. Sowing, fertilization and harvest dates were adapted to climatic conditions or plant development stages during each year (Table 4).

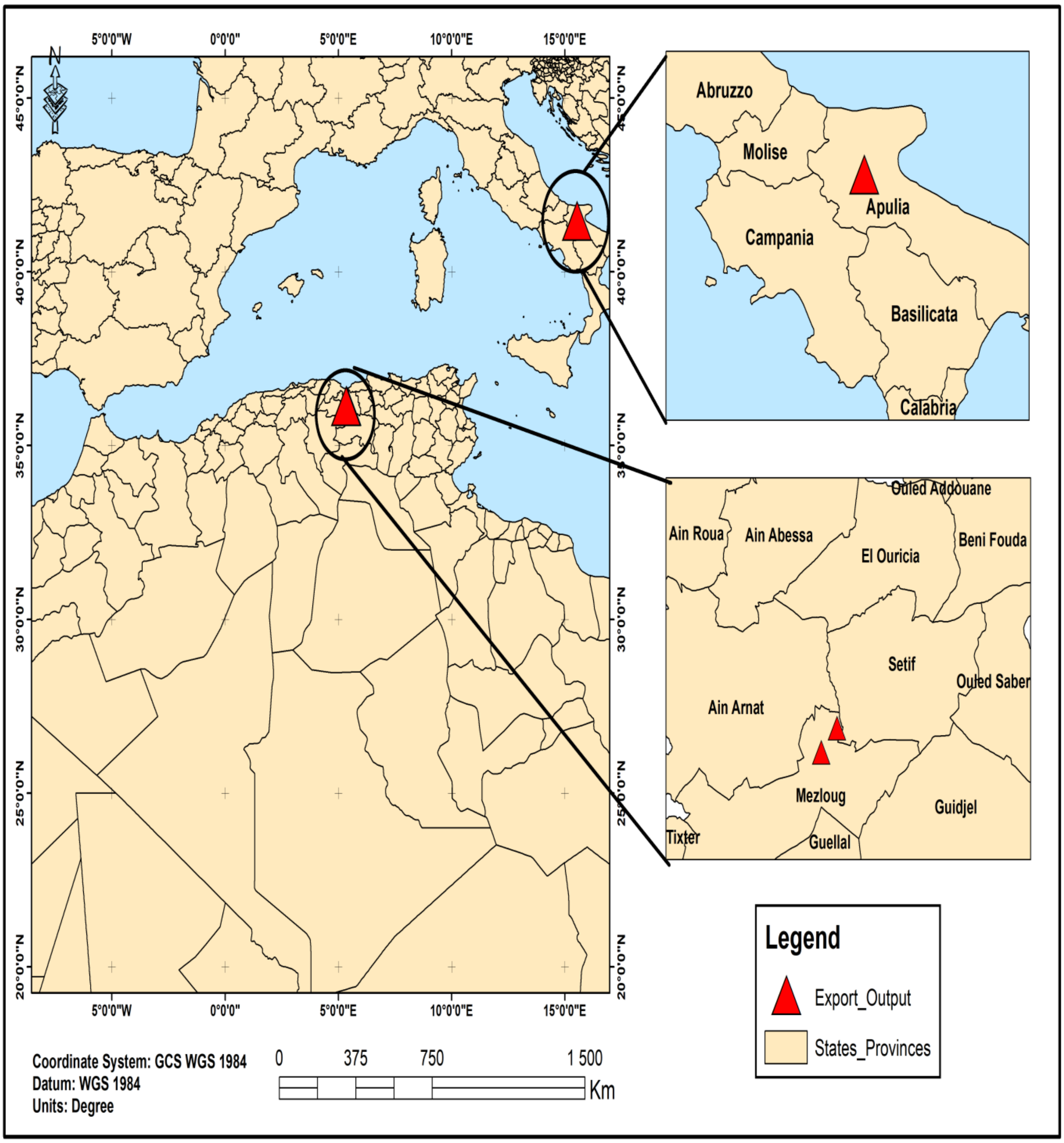


Figure 4. Locations of Experiment trials in Algeria and Italy.

Table 4 . Experimental details and dates of the main phenological stages during the four growth experiments (in separate columns).

		Properties of experimental site			
Coordinates		36° 9’ N, 5°21’ E at Sétif-Algeria	36° 08’ N, 5°20’ E at Sétif-Algeria	36° 08’ N, 5°20’ E at Sétif-Algeria	41° 28’N, 15◦32’ E at Foggia-Italy
Altitude (m)		1000 m	962 m a.s.l.	962 m a.s.l.	75 m a.s.l
Soil texture	Sand %	Nd	40	40	27.36
	Silt %	Nd	4	4	40.3
	Clay %	Nd	56	56	32.33
pH (in H2O)		Nd	8.29	8.29	8.2
Electrical conductivity (mS/cm)		Nd	0.22	0.22	0.18
Organic matter (%)		Nd	1.88	1.88	19.06 g/kg
C/N ratio		Nd	7.81	7.81	0.16 g/kg
Total N (%)		Nd	0.14	0.14	1.31
Exchangeable Phosphorus P (ppm)		Nd	29.8	29.8	11
Exchangeable potassium K (meq/100g)		Nd	1.3	1.3	0.97
Harvest year		2015-2016	2016-2017	2017-2018	2018-2019
Sowing date		03/12/2015	22/12/2016	02/01/2018	07/12/2018
The first N supply at Beginning of tillering		01/02/2016	01/03/2017	17/03/2018	11/02/2019
The second N supply at Beginning of stem elongation		04/04/2018	12/04/2017	19/04/2018	08/04/2019
Flowering		12/05/2016	03/05/2017	13/05/2018	03/05/2019
Harvesting		18/07/2016	22/06/2017	22/06/2018	25/06/2019
Number of days to heading		162	134	133	148

nd= not determined

a.s.l.: above sea level

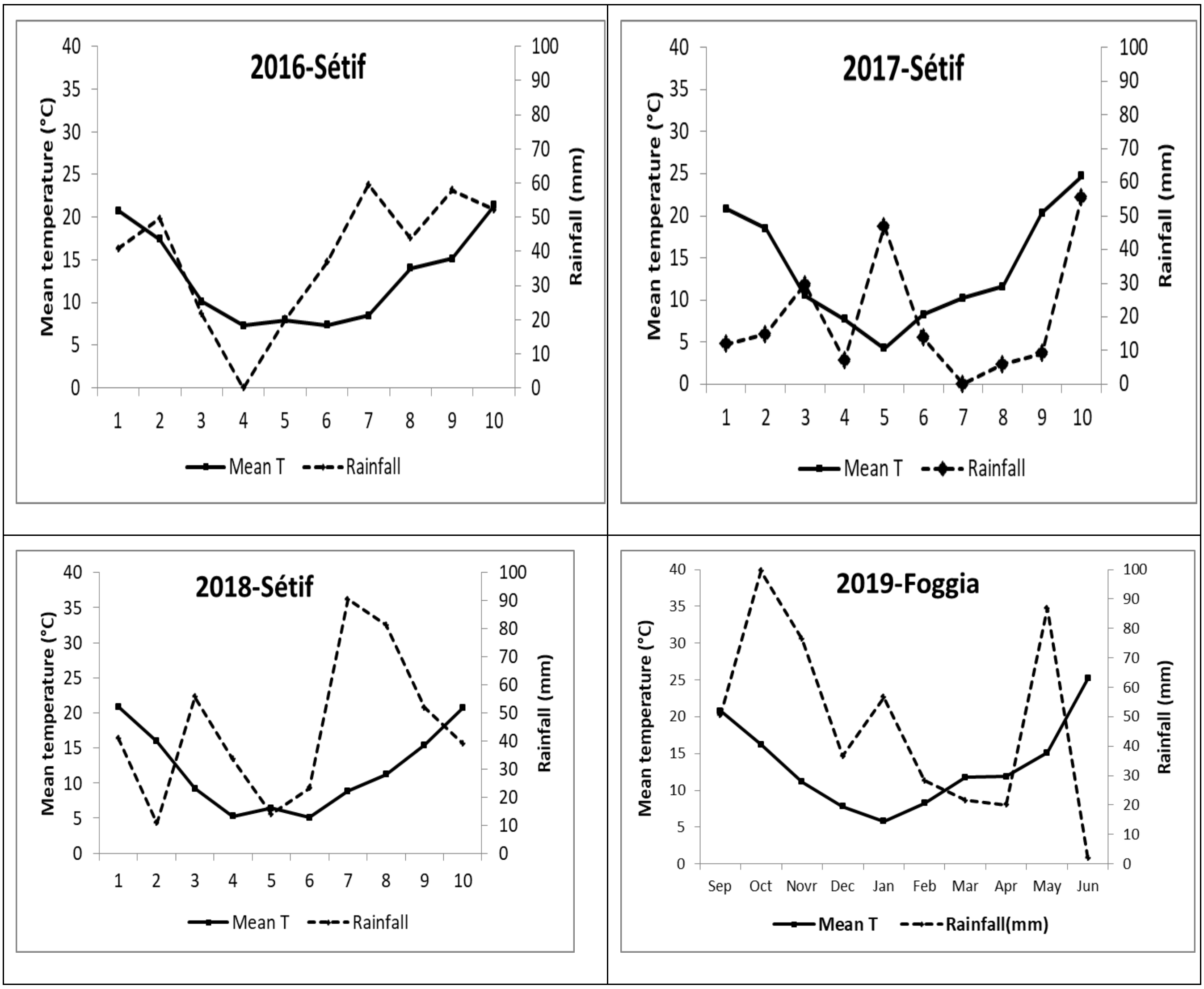


Figure 5 . Monthly precipitation, minimum, maximum and mean temperatures during the three cropping seasons (2016 = 2015/16; 2017 = 2016/17; 2018 = 2017/18; 2019 = 2018/19).

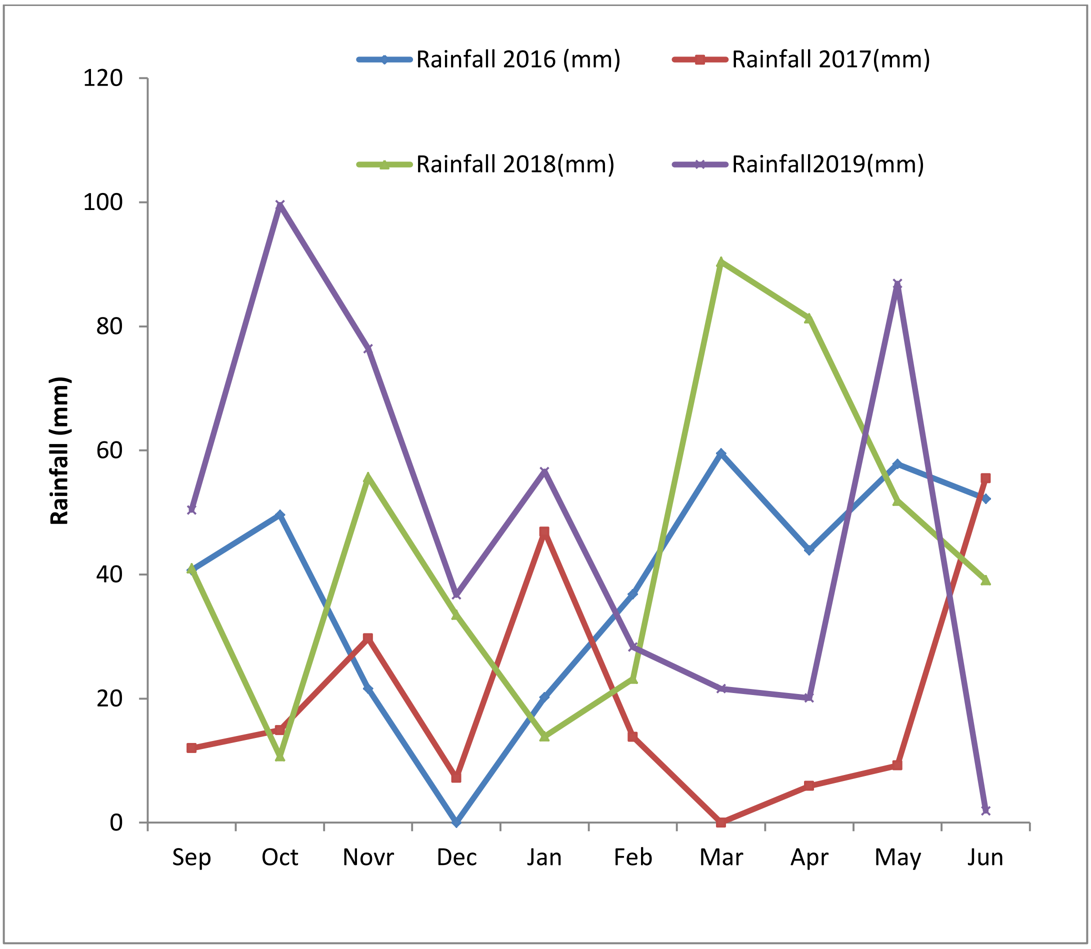


Figure 6 . Rainfall in the 4 years of experimentation

2. EXPERIMENTAL DESIGN AND TREATMENTS DESCRIPTION

The trials were arranged in a split-plot design with 2 factors; Nitrogen level (N) and Genotype (G) and tree blocks and grown in 2.5 m2 plots. Seeds were sown at a density of 300 seeds m-2. Four N rates were applied (N0=0, N1=40, N3=80 and N4=120 UN ha-1, where the total amount was split into 2 timings, the first one (1/3) at the beginning of tillering and the second one (2/3) at the beginning of stem elongation. N was applied as urea (46%). For the second studied factor, seven varieties of durum wheat were used (Table 4), V1: Bousselam, V2: Waha, V3: MBB, V4: Sétifis, V5: Megress, V6: Massinissa and V7: Gtadur. The chosen genotypes are widely grown in Algeria.

Table 5. Origin of the genotypes studied.

Genotypes	Pedigree	Origin
Bousselam	Heider/Martes//Huevos de Oro ICD86-0414-ABL-0TR-4AP-0TR-14AP-0TR	ICARDA-CIMMYT
Waha	PLC/Ruff//Gta/3/RoletteCM 17904-3M-1Y-1M-0Y	ICARDA (Syrie)
MBB	Genealogical selection from a landrace population	ITGC (Setif)
Sétifis	Bousselam/Ofanto	ITGC (Setif)
Megres	Ofanto/Waha//MBB	ITGC (Setif)
Massinissa	Ofanto/Bousselam	ITGC (Setif)
GTAdur	Crane/4/PolonicumPI185309//T.glutin en/2* Tc60/3/Gll	ICARDA-CIMMYT

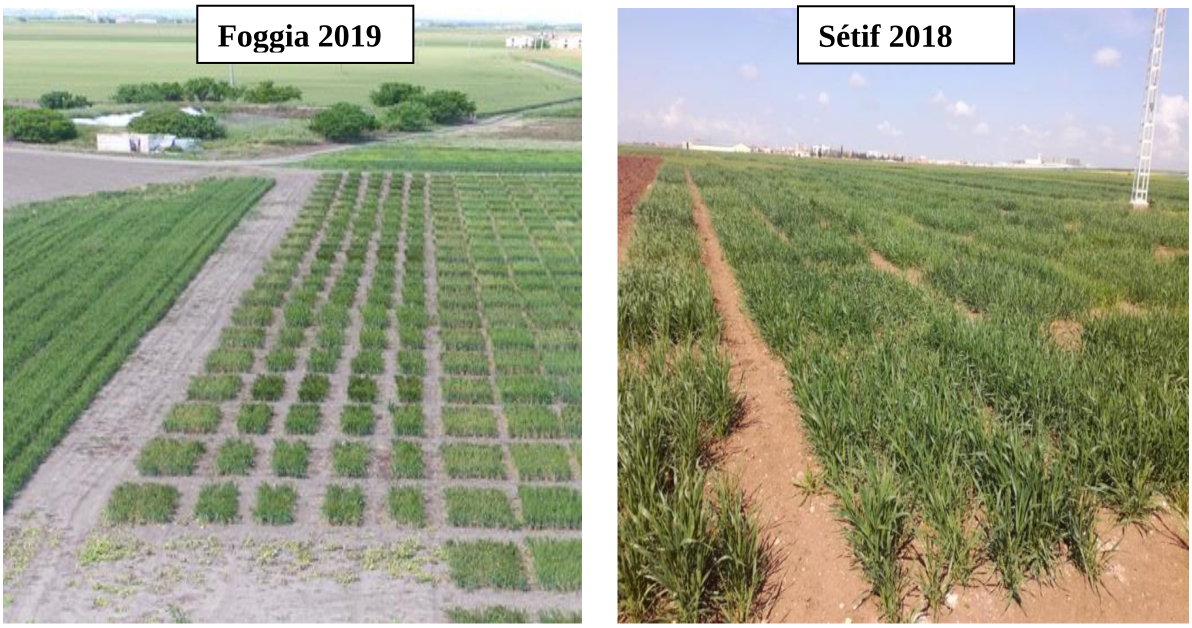


Figure 7. Trials view in growing season 2018 and 2019.

3. MEASURED PARAMETERS

3.1. MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERIZATION

Morphological and physiological characterization was based on 12 quantitative characters, which are: Plant height (PH), Neck length (NL), Spike length (SL) and Awns length (AL), Days to heading (DH) and Filling period (FP). This characterization was performed on the seven varieties: Bousselam, Waha, MBB, Sétifis, Megres, Massinissa and GTAdur . However the others parameters such as:, Number of spikelet per spike (NSpk/S), Spike weight (SW), Number of grains per spike (NG/S), Weight of grains per spike (WG/S), Flag leaf area (FLA) and total chlorophyll in flag leaf (Chlo) were performed on the four varieties: Bousselam, MBB, Megres and GTAdur .

- **Plant height (PH):** Plant height was measured at maturity including stem, spike. The length was taken from the base of the plant to the tip of the highest spike.
- **Neck length (NL):** Neck length was measured at maturity. The length was taken from the stem to the tip of the spike.
- **Spike length (SL):** Five spikes were picked randomly from each plot at maturity, spike length was measured (excluding awns) and the average was recorded.
- **Awns length (AL):** Five spikes were picked randomly from each plot at maturity, awns length was measured and the average was recorded.
- **Number of spikelet per spike (NSpk/S):** Five spikes were harvested randomly from each plot, spiklets on each spike were counted, mean was recorded.
- **Spike weight (SW):** five spikes were harvested randomly from each plot, each spike was weighted and means were recorded.
- **Number of grains per spike (NG/S):** five spikes were harvested randomly from each plot, threshed separately, grains within each spike were counted and means were recorded.
- **Weight of grains per spike (WG/S):** five spikes were harvested randomly from each plot, threshed separately, grains within each spike were weighted and means were recorded.
- **Flag leaf area (FLA):** five leaves were taken randomly from each plot; the length and greatest width of the flag leaf were measured. The leaf area was estimated according to (Spagnoletti Zeuli and Qualset, 1990).

- **Days to heading (DH):** Date of spike emergence was scored when the first spikelet visible on spikes of 50% of the plants, it was converted to days by counting the days from sowing date up to date of 50% spikes emergence.
- **Filling period (FP):** Filling period is the period (in days) between spike emergence and maturity.
- **Total chlorophyll in flag leaf (Chlo**): the chlorophyll content in flag leaf was measured using a Minolta SPAD 502 type chlorophyll meter, and expressed in arbitrary units or CCI (Chlorphyll Content index). The measurement was taken at flowering stage.

3.2. QUALITATIVE CHARACTERIZATION OF GRAIN

The qualitative analysis of grain was made with a cereal analyzer Infratec Foss, based on NIT technology and NIR FOSS xds near infrared (Figure 8). The measure was on the seven varieties which the qualitative traits measured were:

- **Protein content (%)**
- **Dry gluten (DG)**
- **Specific weigh(SpW)**

Figure 8. Grain analyzer InfratecTM FOSS and NIR xds FOSS

3.3. AGRONOMIC CHARACTERIZATION (DRY MATTER, GRAIN YIELD AND ITS COMPONENTS)

At anthesis and harvesting, 0.5 m of three adjacent central rows (an area of 0.3 m2) from each plot were cut at ground level and separated into straw and spike. All samples were dried at 80 °C for 72h to obtain dry weight. At harvesting, after estimating the spikes dry matter, spikes were threshing to recover the grain, which is dried for 72 h at 80 °C and weighed to estimate the grain yield and its components. Finally, all samples were milled and their total N concentration was determined with the Dumas combustion method (ISO/TS 16634-2:2009) (LECO FP-528, Figure 9). The measure of dry matter, grain yield and its components were performed on the seven varieties, the agronomic traits studied were reported in table 5.

Figure 9 . LECO FP-528 per N analysis

3.4. NITROGEN UPTAKE, NITROGEN USE EFFICIENCY AND ITS COMPONENTS

According to Schvartz et *al.*, (2005) and Zuliang Shi et *al*., (2018), nitrogen uptake by the plant corresponds to the quantity of nitrogen taken by it and expressed in kg N per hectare. The calculation of quantity involves the biomass of aerial parts and their total nitrogen content:

N uptake (kg N/ha) = DM en kg/ha * N % / 100. ……. Equation 1

Nitrogen use efficiency (NUE) has been defined by Moll et *al*. (1982) as grain yield per unit of available N (soil + fertilizer N or as fertilizer N). They also proposed that NUE can be partitioned into the components of N uptake efficiency (UPE, plant N per unit of either soil + fertilizer N or only fertilizer N) and N utilization efficiency (UTE, grain yield per unit of N in the plant); the product of these two components results in NUE. According to (Moll et *al*., 1982)

Nitrogen use efficiency (NUE, kg kg-1) = Gy / N supply ……. Equation 2

Nitrogen uptake efficiency: NUpE = N in plant/N supply=NM/Ns ……. Equation3

Nitrogen utilization efficiency: NUtE = grain yield/N in plant =GY/NM ……. Equation 4

According to Giambalvo et *al*., (2004, 2010) ; Limon-Ortega et *al*., (2000)

Ns: N supply was defined as the sum of (i) N applied as fertilizer and (ii) total

N uptake in control (0 N applied).

N supply: Ns = Nt0 + Nf ; where: Nt0 = aboveground plant N in control plots (0 applied N) ; Nf = applied N.

The measure of nitrogen uptake, nitrogen use efficiency and its components were performed on the four varieties, the traits studied were reported in table 5.

3.5. ECONOMIC ASPECTS

The marginal net return (MNR) was calculated as follows:

MNR = (Yield × Price) – (N fertilization × Cost)

Where Yield was the marketable yield for each treatment, Price was the price paid for yield (45 000 DZD, 280, 31 eurot−1), N fertilization was the N fertilizer amount given, and Cost was the cost of the N fertilizer (66000 DZD, 417, 35 euro t−1 for urea 46%). The Price and the Cost were indicative costs for the last few years (LOUAHDI Naserddine, personal communication). The measure of marginal net return (MNR) was performed on the seven varieties.

Table 6. Description of measured and calculated agronomic traits.

Trait	**Description**	**Formula**	**Units**
DMS-F	Dry matter of spikes at flowering		kg ha^{-1}
DMST-F	Dry matter of straw at flowering		kg ha^{-1}
DMF	Total dry matter at flowering	DMS-F+ DMST-F	kg ha^{-1}
DMS-M	Dry matter of spikes at maturity		kg ha^{-1}
DMST-M	Dry matter of the straw at maturity		kg ha^{-1}
DMM	Total dry matter at maturity	DMS-M + DMST-M	kg ha^{-1}
GY	Grain yield		kg ha^{-1}
NbrS m^{-2}	Number of spikes m^{-2}		
TGW	Thousand grain weight		(g)
HI	Harvest index	GY DMM^{-1}	%
NG	Nitrogen uptake by grain		kg N ha^{-1}
NST-M	Nitrogen uptake by straw at maturity		kg N ha^{-1}
NM	Total nitrogen uptake at maturity	NST-M + NG	kg N ha^{-1}
NHI	Nitrogen harvest index	NG NM^{-1}	
NUE	Nitrogen use efficiency	GY N $supply^{-1}$	kg kg^{-1}
NUpE	Nitrogen uptake efficiency	NM N $supply^{-1}$	kg kg^{-1}
NUtE	Nitrogen utilization efficiency	GY NM^{-1}	kg kg^{-1}
MNR	Marginal net return	(Yield×Price)−(Nfertilization×Cost)	€ t^{-1} DZD t^{-1}

4. STATISTICAL ANALYSIS

4.1. ANALYSIS OF VARIANCE ANOVA

The collected data were statistically analyzed by the GLM model of SAS software, version 9.1.3, (SAS Institute, Cary, NC). Treatment means were compared with the least significant difference (LSD) at the 0.05 probability level with Fisher's LSD test.

4.2. ANALYSIS OF CORRELATIONS

The correlation analysis of the different variables was performed using the Pearson test. Two methods of statistical analysis were used to study the effects of year (Y), N rate (N), genotype (G) and their interactions.

4.3. ANALYSIS OF COVARIANCE ANCOVA

Each combination of location and growing season was treated as an environment, and the analysis of covariance (ANCOVA) was performed using R software, version 3.5.3, where the independent variables were the genotypes (G), N level (N), the total rainfall in vegetative period (RVP), the total rainfall in flowering and filling period (RFFP), and the mean temperature (MT). They served as covariates.

CHAPTER 3: RESULTS AND DISCUSSION

1. WEATHER CONDITIONS

1.1. WEATHER CONDITIONS IN THREE GROWING SEASON IN ALGERIA (2016-2018)

In the three growing season in Algeria, the trials were in semi-arid region in Sétif with low rainfall (an average of 21 years of annual rainfall is 359.3 mm). The deficit is 20% to the normal average (450mm), the total rainfall in the three experimental years was 382.3 mm, 195.12 mm and 440.7mm respectively in 2015/16-2016/17-2017/18 with a deficit of 15%, 57% and 2%. Therefore 2016/17 is a too dry year, in addition, rains were badly distributed throughout the cycle: An excess of rains during the vegetative phase, and a severe deficit at the flowering stage and during grain filling.

Rainfall between emergence and anthesis (Jan-April) was varying appreciably between years of cultivation, totaling 160.4 mm, 66.62 mm and 208.8 mm in 2015/16, 2016/17 and 2017/18 respectively. Rainfall during grain filling was also different, 2015/16 (110mm), 2016/17 (64.7mm) and 2017/18 (91mm). For both years 2015/16 and 2017/18 rainfall in the period of emergence-anthesis and during grain filling was higher than the long-term average, while in the second year 2016/17, it was much lower than long-term average. The mean monthly temperature was similar in the 3 years and similar to the long-term average, but wide fluctuations were observed particularly in the last period of the growing season with lower temperatures in the first and last year and higher temperatures in the second year.

1.2. WEATHER CONDITIONS IN ITALY IN GROWING SEASON (2019)

In the growing season 2018–2019, in Italy, the trail was in a Mediterranean climate in Foggia, characterized by wide variation in quantity and distribution of rainfall (Tubiello et *al*., 2000; De Vita et *al*., 2007). The long-term average of 59 years of annual rainfall is 472 mm, which is higher than the normal average.

The total rainfall received overall during the 2018–19 crop cycle exceeded the long-term average of 543 mm; in addition, rains were well distributed throughout the cycle compared to the Sétif region.

Rainfall between emergence and anthesis (January–April) was 126.6 mm, and rainfall during grain filling was 91 mm. The mean monthly temperature was 13.39°C.

2. MORPHOLOGICAL, PHYSIOLOGICAL AND QUALITATIVE TRAITS CHARACTERIZATION

Fifteen characters were studied covering morphological, physiological and qualitative traits at different growth stages and plant parts including intact plant, spikes and grains, this evaluation were conducted at Foggia for one growing season (2018-2019). Mean values of different traits measured and their statistical significances are presented in table 7, 8 and 9.

Table 7. Means and ANOVA results of morphological and qualitative traits measured in 7 genotypes.

		PH(cm)	**NL(cm)**	**SL (cm)**	**AL(cm)**	**P %**	**DG%**	**SpW(kg.hl^{-1})**
Effect Nitrogen level (N)	0	84.03	29.47	6.96	10.64	15.33	12.93	78.63
	40	81.93	28.80	6.84	10.89	15.33	13.15	78.95
	80	83.15	29.50	6.88	11.03	15.32	13.32	78.12
	120	82.96	28.53	6.84	10.94	16.13	13.94	78.36
Test F	**P**	**0.6432NS**	**0.5252NS**	**0.7645NS**	**0.1595NS**	**0.0017****	**0.0905NS**	**0.3816NS**
Effect Genotype (G)	Bousselam	77.91	29.77	6.80	11.30	15.82	13.82	77.59
	GTAdur	76.52	27.27	7.41	10.09	15.15	12.70	80.30
	MBB	99.52	31.97	6.14	9.93	15.07	13.27	81.68
	Massinissa	82.08	27.83	6.85	11.78	15.32	12.17	76.38
	Megress	85.52	28.40	6.72	10.72	15.50	13.80	78.31
	Sétifis	80.55	30.54	7.05	11.40	15.89	13.32	77.67
	Waha	79.02	27.75	7.18A	10.92	15.94	14.26	77.69
Test F	**P**	**<.0001*****	**0.0002****	**<.0001*****	**<.0001*****	**0.0263***	**0.0051***	**<.0001*****
G*N	P	0.6406NS	0.3148NS	0.9424NS	0.4038NS	0.9769NS	0.9815NS	0.9892NS
	Means	**83.02**	**29.07**	**6.88**	**10.88**	**15.53**	**13.33**	**78.52**
	CV%	6.34	8.81	5.99	5.24	4.95	9.93	2.05

PH: Plant Heigh(cm), NL: Neck lenght(cm), SL: Spike lenght (cm), AL: Awns lenght(cm), P%: Proteine (%), DG:Dry gluten (%), SpW: Specific Weight (kg.hl^{-1}). NS= no significant value, *= significant value at P <0.05, **= significant value at P <0.01, ***= significant value at P <0.001, CV%= Coefficient of variation.

Table 8 . Means and ANOVA results of morphological and physiological traits measured in 4 genotypes.

		NSpk/S	**SW(g)**	**WG/S(g)**	**NG/S**	**FLA(cm^2)**	**Chlo (CCI)**
Effect Nitrogen level (N)	0	11.00	2.74	1.72	54.50	30.09	637.16
	40	10.58	2.74	1.73	54.25	24.76	619.58
	80	11.08	2.95	1.97	58.58	26.49	648.66
	120	11.00	2.97	1.85	52.33	27.37	632.08
Test F	**P**	**0.42 NS**	**0.5676NS**	**0.6072NS**	**0.6482 NS**	**0.2513NS**	**0.4131NS**
Effect Genotype (G)	Bousselam	10.41	2.93	1.90	59.00	29.74	625.83
	GTAdur	11.16	2.88	1.83	56.58	27.90	669.75
	MBB	10.66	2.89	2.00	50.00	26.03	627.75
	Megress	11.41	2.71	1.53	54.08	25.03	614.16
Test F	**P**	**0.0181***	**0.7673NS**	**0.1567NS**	**0.3300NS**	**0.3063NS**	**0.0158***
G*N	P	0.0714NS	0.0193*	0.1748NS	0.3249NS	0.5268NS	0.9627NS
	Means	**10.91**	**2.85**	**1.82**	**54.91**	**27.18**	**634.37**
	CV%	7.36	18.74	28.37	22.24	23.69	6.64

NSpk/S: Number of spikelet per spike, **SW**: Spike weight (g), WG/S: weight of grains per spike**(g)**, **NG/S:** Number of grains per spike, **FLA**:Flag leaf area (cm), **Chlo**: Total chlorophyll in flag leaf (CCI: Chlorphyll Content index). NS= no significant value, *= significant value at P <0.05, **= significant value at P <0.01, ***= significant value at P <0.001, CV%= Coefficient of variation.

Table 9. Means and ANOVA results of number of days to heading and filling period.

		DH(j)	FP(j)
Effect Genotype (G)	Bousselam	144	57
	GTAdur	141	60
	MBB	148	53
	Massinissa	140	61
	Megress	147	56
	Sétifis	143	58
	Waha	142	59
Test F	P	<.0001***	<.0001***
	Means	143.57	57.71

DH: Days to heading (J), **FP**: Filling period (J), ***= significant value at P <0.001.

2.1. MORPHOLOGICAL AND PHYSIOLOGICAL TRAITS CHARACTERIZATION

2.1.1. Plant height (PH)

The effect of N level on plant height (PH) was not significant (Table 7), however very highly significant difference was detected among the 07 genotypes. The average was 83.02 cm. with high variations ranging from a minimum of 76.52 cm measured in the genotype GTAdur, to a maximum of 99.52 cm measured in the genotype MBB (Table 7, figure 10).

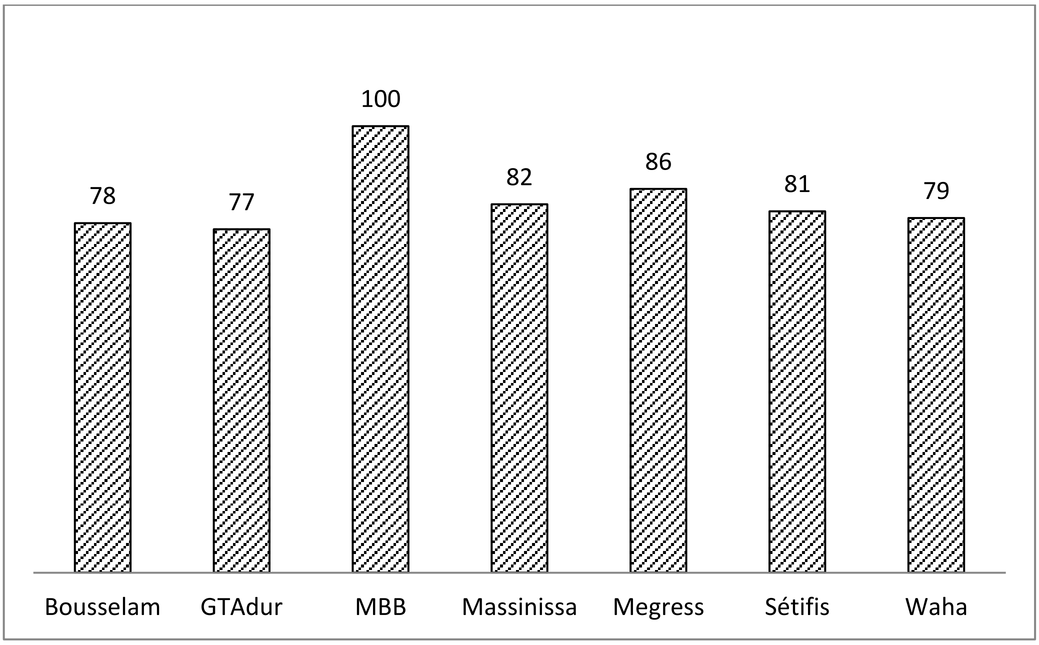


Figure 10. Plant height (cm) in the 07 genotypes studied.

The comparison of mean height plant indicated the presence of 3 different groups:

- The tall genotypes represented by MBB (99.52 cm), Megress (85.52cm) and Massinissa (82.08).
- Medium genotypes represented by Sétifis (80.55 cm) and Waha (79.02)
- The short genotypes represented by Bousselam (77.91 cm) and GTAdur (76.52cm).

On this subject, the results obtained by Eid (2009) showed that the height plant in wheat is strongly affected by drought, however, varieties adapted to drought are often shorter than those that have adapted to optimal moisture conditions.

2.1.2. Neck length (NL)

For the neck length (NL), no significant nitrogen level effect was detected. However it varied significantly among the 07 genotypes (Table 7, figure 11). The average was 29.07 cm. The genotype MBB showed the highest mean neck length (31.97cm) while GTAdur had the lowest neck length (27.27 cm).

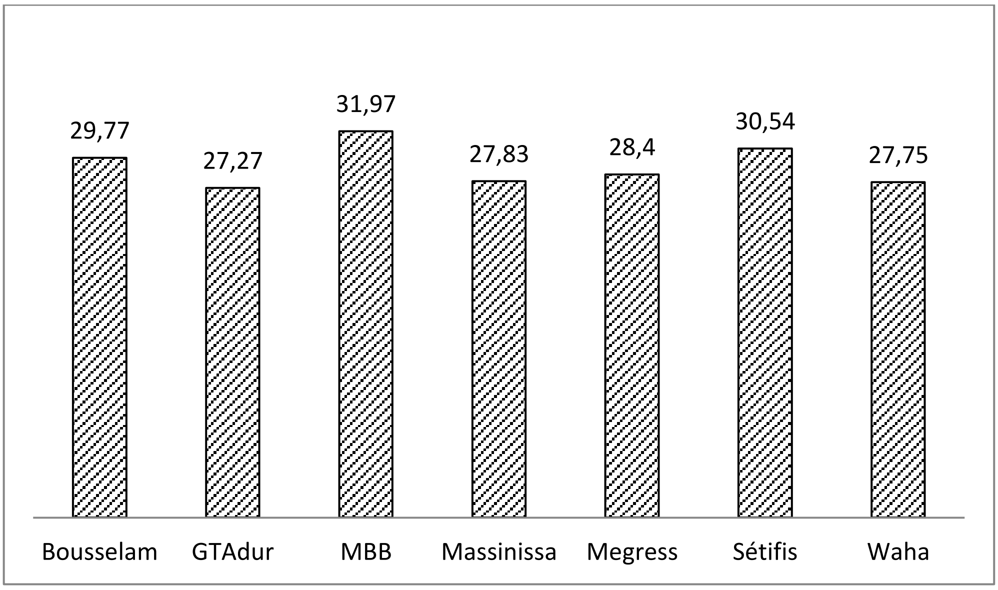


Figure 11. Neck length (cm) in the 07 genotypes studied.

2.1.3. Spike length (SL)

The effect of N level on spike length (SL) was not significant (Table 7). However the 07 genotypes showed very highly significant variation (Table 6, figure 12). The average was (06.88 cm). GTAdur had the most spike length (07.41 cm) while MBB had the fewest spike length (06.14 cm). This result reveals the genetic variability of these varieties.

The comparison of mean spike length indicated the presence of 3 different groups:

- Genotypes showed with long spikes were GTAdur (7.41cm), Waha (7.18 cm), Sétifis (7.05cm) and Massinissa (6.85cm)
- Genotypes showed with medium spikes were Megress (6.72cm) and Bousselam (6.80cm).
- Genotypes showed with shorter spikes were MBB (6.14cm).

2.1.4. Awns length (AL)

For the awns length (NL), no significant nitrogen level effect was detected. However, awns length varied significantly among the 07 genotypes with 10.88 cm as average (Table 7, figure 12. Massinissa genotype had the tallest awns (11.78 cm) while MBB had the shortest awns (09.93 cm).

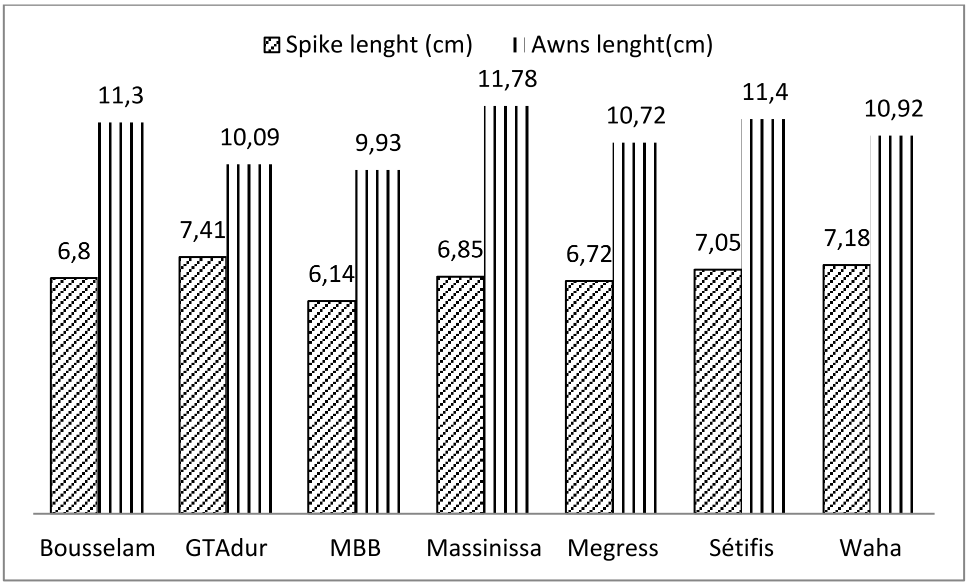


Figure 12. Spike length and Awns length (cm).

2.1.5. Number of spikelet per spike (NSpk/S)

The number of spikelet per spike (NSpk/S) was not affected by nitrogen level. However the 04 genotypes showed significant variation in terms of number of spikelets per spike (Table 8). The average of spikelets per spike was 10.91. Megress had the most spikelets number per spike (11.41), while Bousselam had the least number (10.41).

2. 1. 6. Spike weight (SW)

The results showed that the spike weight (SW) was not affected by nitrogen level and by genotypic variability. The mean weight of spike was 2.85 g, it rather stable, fluctuating only between 2.74 g and 2.95 g at the different N levels and in different genotypes (Table 8).

2.1.7. Weight of grains per spike (WG/S)

The results showed that the weight of grains per spike (WG/S) was not affected by nitrogen level and by genotypic variability. The mean weight of grains per spike was 1.82g, it rather stable, fluctuating only between 1.72g and 2g at the different N levels and in different genotypes (Table 8).

2.1.8. Number of grains per spike (NG/S)

The results showed that the number of grains per spike (NG/S) was not affected by nitrogen level and by genotypic variability. The mean number of grains per spike was 59.91 grains per spike, it rather stable, fluctuating only between 50 and 59 at the different N levels and in different genotypes (Table 8).

2.1.9. Flag leaf area (FLA)

The results showed that the flag leaf area (FLA) was not affected by nitrogen level and by genotypic variability. The mean flag leaf area (FLA) was 27.18 cm2, it rather stable, fluctuating only between 24.76 and 30.09 at the different N levels and in different genotypes (Table 8).

2.1.10. Total chlorophyll in flag leaf (Chlo)

The effect of N level on total chlorophyll in flag leaf was not significant. However the 04 genotypes showed significant variation (Table 7). The average was (634.37 CCI). GTAdur had the most value (669.75 CCI) while Megress had the fewest value (614.16 CCI).

2.1.11. Days to heading (DH)

The number of days from sowing to heading is shown in table 9, the results showed very highly significant variation in number of days to heading. The mean was 143.57 days. Massinissa(140), GTAdur(141), Waha(142), Sétifis(143) and Bousselam(144) were the earliest genotypes, while Megress(147) and MBB(148) were the latest genotypes to heading. This wide range of days needed from sowing to spike emergence (08 days) reflects the genetic variations between different genotypes. Our results showed that Massinissa, GTAdur, Waha, Sétifis and Bousselam were earlier genotypes compared to Megress and MBB which were late in days to heading.

2.1.12. Filling period (FP)

The days from heading date to fully maturity (Filling Period of spikes) varied significantly among the studied genotypes (Table 9). The average of days required by genotypes for grain filling was (57.71 days). MBB required the fewest days (43) while Massinissa took the most days (61).

2.2. QUALITATIVE TRAITS CHARACTERIZATION

Three characters were studied covering qualitative traits of grains, this evaluation were conducted at Foggia for one growing season (2018-2019). Mean values of qualitative traits measured and their statistical significances are presented in Table 7.

2.2.1. Proteins content (P %)

The results showed that the proteins content was improved significantly by nitrogen level increase (Table 7, figure 13). The best proteins content was 16,13 %. The same the for the genotype effect, the results showed a significant genotypic variation.

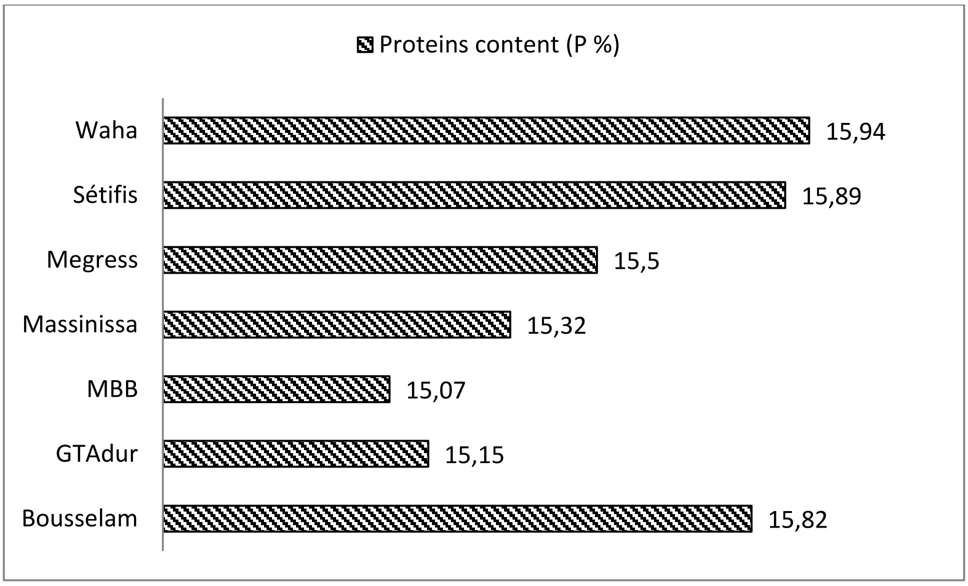


Figure 13 . Proteins content (P %) in the 07 genotypes studied.

2.2.2. Dry gluten (DG)

The results showed that the dry gluten was not affected by nitrogen level. However the 07 genotypes showed significant variation in terms of dry gluten (Table 7, Figure 14). The mean was 13.3%.

2.2.3. Specific weight (SpW)

The results showed that the dry gluten was not affected by nitrogen level. However the 07 genotypes showed significant variation in terms of dry gluten (Table 6, Figure 14). The mean was 78.52 kg.hl-1.

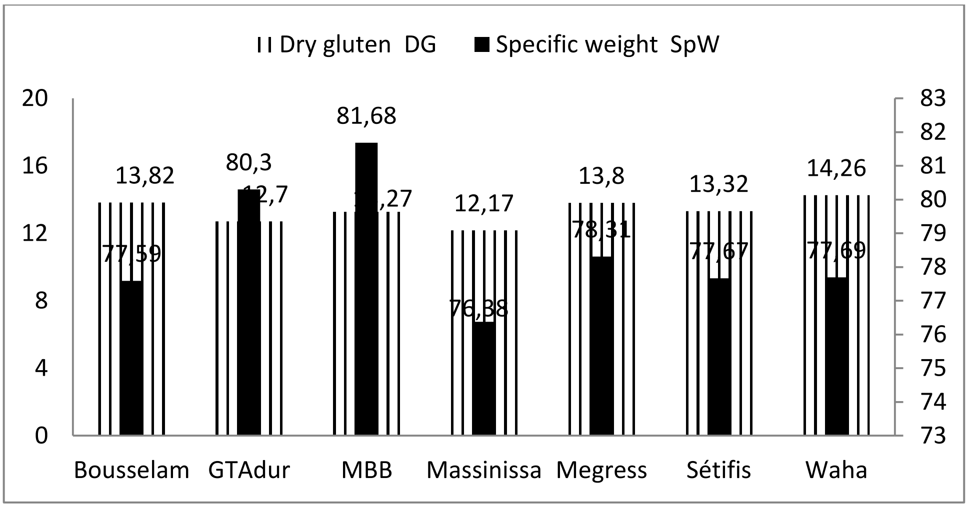


Figure 14. Qualitative traits characterization in the 07 genotypes studied.

2.3. DISCUSSION

Breeding strategies exploits a wide range of morphological, physiological and qualitative distinctness between various genotypes which they might be used in genetic improvement programs. In our study, fifteen characters were studied covering morphological, physiological and qualitative traits which provide a good background for future studies. The objective was to evaluate the genotypic variation and the N effect on these traits.

Our results showed a significant genotypic variation for: Plant height (PH), Neck length (NL), Spike length (SL), Awns length (AL), Days to heading (DH) and Filling period (FP), Number of spikelet per spike (NSpk/S) and total chlorophyll in flag leaf (Chlo), Protein content (P %), Dry gluten (DG), Specific weigh(SpW) . However, no effect of genotype was detected for: Spike weight (SW), Number of grains per spike (NG/S), Weight of grains per spike (WG/S), Flag leaf area (FLA).

For the N effect, no significant effect was detected for all traits studied except for protein content (P %) which was highly significant.

For the genotypic variation, our results are in agreement with the results obtained by (Derbal et *al.*, 2013; Nora et *al.*, 2015), where they found high variations in most Algerian durum wheats for several quality traits.

3. AGRONOMIC AND ECONOMIC ASPECTS

3.1. DRY MATTER ACCUMULATION (STRAW, SPIKE AND TOTAL DRY MATTER ACCUMULATION)

The dry matter produced at maturity is of considerable importance in the study region, where farmers practice cereal-livestock association. The mean values of dry matter of straw (DMST) and spike (DMS), as well as the total dry matter accumulated at the flowering stage (DMF) and at maturity (DMM) and their statistical significances are mentioned in table 10.

The results over the three years of experimentation indicated highly significant differences among genotypes (G) and years (Y) for all investigated parameters excepted DMF between genotypes (P=0.0688, table 10).

N level (N) affected the dry matter of straw at maturity (DMST-M, P=0.0221, table 10), dry matter of spike at flowering (DMS-F, table 10) and total dry matter at flowering (DMF, P=0.0290, table 10. Moreover, there were significant interactions between Y*G for all measured parameters and N*G for DMS-M and DMM, however, the Y*G*N interaction was never significant (Table 10).

The highest total dry matter production at maturity (DMM) was obtained in 2015/16 with an average of 8689.93 kg ha-1 against 2522.61 and 7678.96 kg ha-1 in 2016/17 and 2017/18, respectively.

The effect of N level on total dry matter (DMM) was not significant (Table 10), however the total dry matter accumulated at flowering (DMF) was affected positively and was increased on average of 5% compared to N1 (Figure 15). This positive difference was essentially due to the increase of dry matter of spike (15%), from 908.99 at N0 to 1092.06 kg ha-1 at N3.

The genotype effect indicated significant differences in the dry matter production capacity and its distribution between straw and spike. The short and medium, genotypes Bousselam, GTAdur, Sétifis and Waha exhibited the lowest total dry matter at maturity (DMM) with values of 5951.38, 5985.18, 6128,24 and 6287.96 kg ha-1 respectively, compared to the tall ones MBB, Massinissa and Megress which produced 6694.90, 6493.98 and 6488.42 kg ha-1, respectively. The tall genotypes showed a positive response to N level, and they increased the total dry matter (DMM) from N0 to N3 (Figure 16.).

Table 10. Means and ANOVA results of dry matter accumulated at flowering and maturity.

		DMST-F (kg ha-1)	DMST-M (kg ha-1)	DMS-F (kg ha-1)	DMS-M (kg ha-1)	DMF (kg ha-1)	DMM (kg ha-1)
Effect Years (Y)	2016	5469.24	4385.71	1450.39	4282.73	6919.64	8668.45
	2017	1400.00	1098.41	516.66	1424.20	1916.66	2522.61
	2018	3276.58	3386.90	1092.06	4292.06	4368.65	7678.96
Test F	**P**	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***
Effect Nitrogen level (N)	0	3210.58	2842.59	908.99	3366.93	4119.57	6209.52
	40	3332.01	2856.87	998.41	3249.47	4330.42	6106.34
	80	3469.31	3034.65	1079.36	3378.04	4548.67	6412.69
	120	3515.87	3093.91	1092.06	3337.56	4607.93	6431.48
Test F	**P**	**0.1724NS**	**0.0221***	**<.0001*****	**0.6261NS**	**0.0290***	**0.2440NS**
Effect Genotype (G)	Bousselam	3264.35	2938.88	941.20	3012.50	4205.55	5951.38
	Waha	3517.59	2797.68	1266.20	3490.27	4783.79	6287.96
	MBB	3887.50	3688.42	685.18	3006.48	4572.68	6694.90
	Sétifis	3161.11	2787.96	1012.50	3340.27	4173.61	6128.24
	Megress	3458.79	2868.51	1060.18	3619.90	4518.98	6488.42
	Massinissa	3286.11	2919.90	1110.18	3574.07	4396.29	6493.98
	GTAdur	3098.14	2697.68	1062.50	3287.50	4160.64	5985.18
Test F	**P**	**0.0021****	**<.0001*****	**<.0001*****	**<.0001*****	**0.0688NS**	**0.0219***
Y*N	**P**	0.8118NS	0.0486*	0.0003**	0.4432NS	0.3540NS	0.3301NS
Y*G	**P**	0.0091**	<.0001***	0.0006***	0.0008***	0.0066***	0.0002***
G*N	**P**	0.3781NS	0.0531*	0.1367NS	0.0071**	0.2684NS	0.0130*
Y*G*N	**P**	0.8288NS	0.7871NS	0.6311NS	0.5429NS	0.7679NS	0.6494NS
	Means	**3381.94**	**2957.01**	**1019.70**	**3333.00**	**4401.65**	**6290.01**
	CV%	25.02	18.69	22.44	18.14	22.88	16.88

DMST-F= Dry matter of straw at flowering (kg ha^{-1}), **DMS-F=** Dry matter of spike at flowering (kg ha^{-1})**, DMST-M=** Dry matter of straw at maturity (kg ha^{-1})**, DMS-M=** Dry matter of spike at maturity (kg ha^{-1})**, DMF =** Total dry matter at flowering (kg ha^{-1}), **DMM=** Total dry matter at maturity (kg ha^{-1}), **NS=** no significant value, ***=** significant value at P <0.05, ****=** significant value at P <0.01, *****=** significant value at P <0.001, **CV%=** Coefficient of variation, **LSD=** last significant difference.

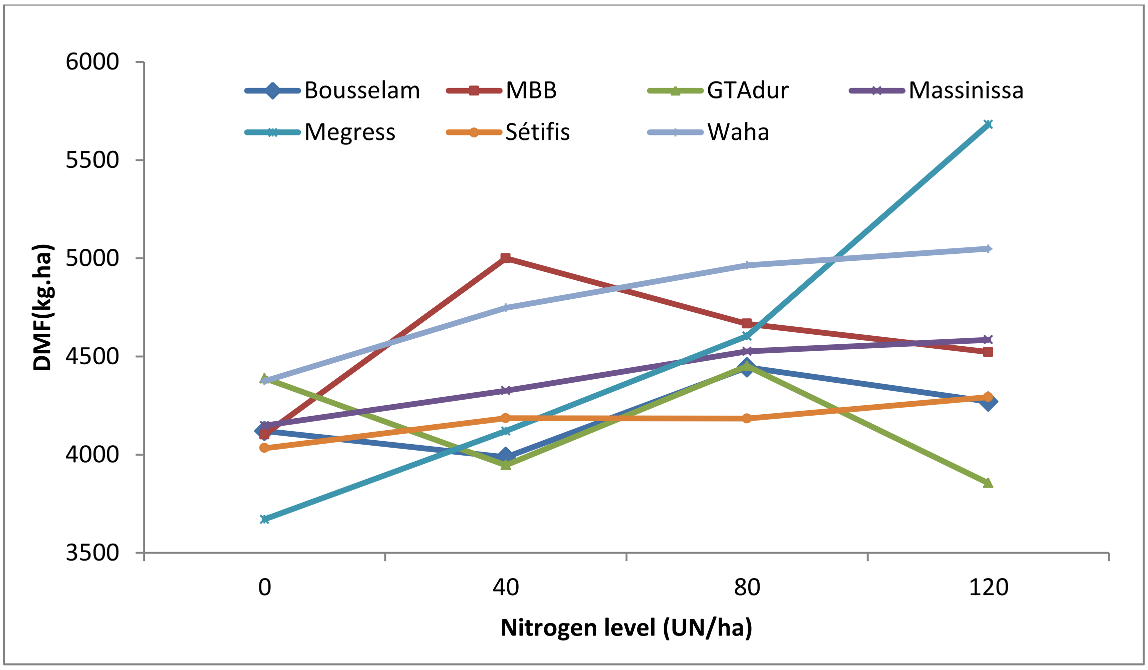


Figure 15. Nitrogen effect on dry matter at flowering DMF

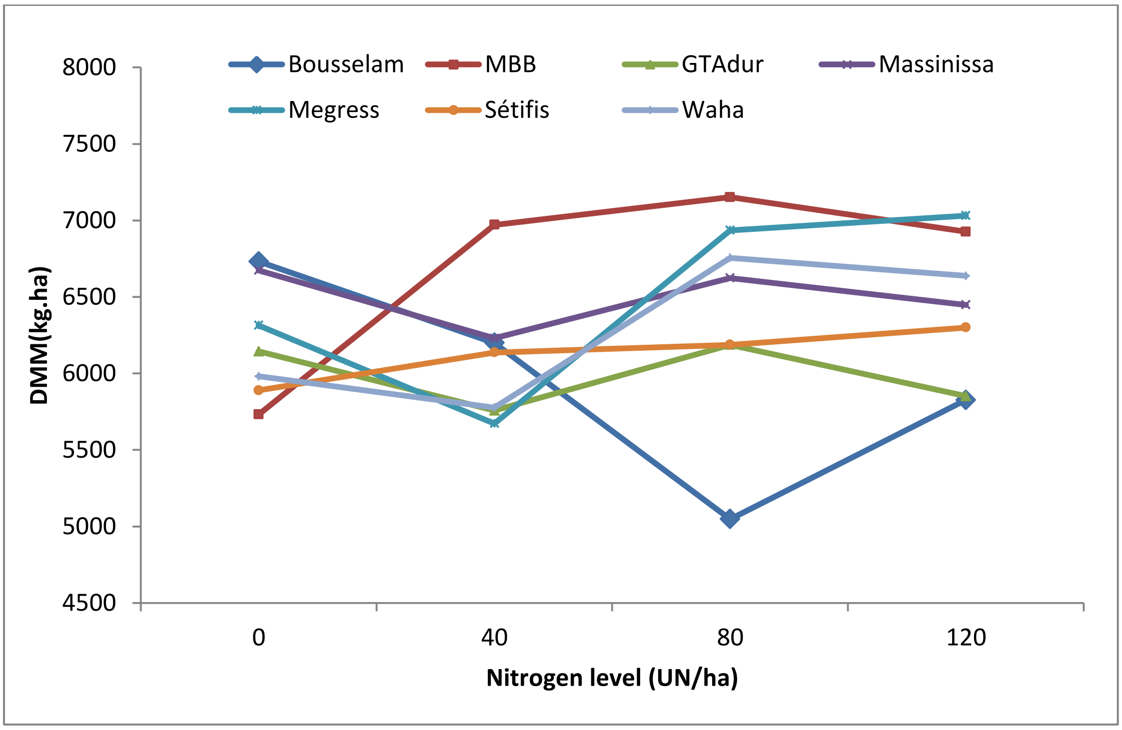


Figure 16. Nitrogen effect on dry matter at maturity DMM

3.2. GRAIN YIELD AND YIELD COMPONENTS

Grain yield in wheat is the product of a series of components: number of plants/m2 * number of spike/plant * number of grains/spike * weight of a grain (Hamadache, 2013). Each of them develops in a different phase of the growing cycle and enters in competition with each other, but the intensity of this competition will depend on the conditions of growth (radiation, water, nitrogen) and variety (Deswarte, 2014). Mean yield values and its components with their statistics interpretations are recorded in the table below (Table 11).

Table 11. Means and ANOVA results of grain yield and its components.

		GY(kg ha-1)	NbrS/m2	TGW(g)	HI	MNR(DZD t−1)	MNR(euro t−1)
Effect Years (Y)	2016	2748.01	262.79	38.35	31.78	119700.71	745.25
	2017	901.78	185.55	32.16	35.57	36620.35	227.73
	2018	2881.34	317.34	40.24	37.56	125700.71	782.62
Test F	**P**	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***
Effect Nitrogen level (N)	0	2243.91	240.15	39.23	35.97	100976.19	628.99
	40	2114.81	246.42	37.27	34.81	92526.66	576.10
	80	2206.08	258.46	35.92	34.94	93993.81	584.99
	120	2143.38	275.87	35.24	34.17	88532.38	550.73
Test F	**P**	**0.3909NS**	**<.0001*** **	**<.0001*** **	**0.2652NS**	**0.0101***	**0.0054****
Effect Genotype (G)	Bousselam	1893.51	290.74	36.62	33.12	81248.33	505.73
	Waha	2312.50	276.20	34.15	37.22	100102.50	623.17
	MBB	1931.01	235.83	37.19	29.66	82935.83	516.24
	Sétifis	2211.11	257.96	34.75	35.31	95540.00	594.75
	Megress	2396.29	256.20	42.50	37.76	103873.33	646.66
	Massinissa	2321.75	227.77	37.77	35.32	100519.16	625.77
	GTAdur	2173.14	241.89	35.45	36.42	93831.66	584.11
Test F	**P**	**<.0001*** **	**<.0001*** **	**<.0001*** **	**<.0001*** **	**<.0001**	**<.0001*** **
Y*N	**P**	0.6699	0.2179	<.0001	0.0846	0.6699	0.5867
Y*G	**P**	<.0001	<.0001	0.0006	0.0013	<.0001	<.0001
G*N	**P**	0.0157	0.2557	0.3744	0.2574	0.0157	0.0082
Y*G*N	**P**	0.1605	0.0869	0.1936	0.6550	0.1605	0.0831
	Means	**2177.05**	**255.23**	**36.92**	**34.97**	**94007.26**	**585.20**
	CV%	21.30	17.59	8.98	14.68	22.20	20.64

GY= Grain yield (kg ha^{-1}), **NbrS m^{-2}=** Number of spike m^{-2} , **TGW=** Thousand grain weight (g), **HI=** Harvest index (%),MNR(DZD t−1)= Marginal net return (algerian dinar t−1), **MNR** = Marginal net return (euro t−1), **NS=** no significant value, ***=** significant value at P <0.05, ****=** significant value at P

<0.01, *****= significant value at P <0.001, **CV%=** Coefficient of variation, **LSD=** last significant difference.

The grain yield was similar during the seasons 2015/16 and 2017/18, and significantly lower in 2016/17. The highest values of grain yield (2881.34 kg ha-1), NbrS m-2 (317.34), TGW (41.24 g) and HI (37.56%) were in third year (2017/18). On the other hand, during the driest year (2016/17), grain yield was decreased by -68% than the average of the other two years (Figure 17).

The response of grain yield to increasing N level was not significant; however the number of spikes per m^2 was affected positively with increase of 13%. TGW was negatively affected by N increase; TGW was significantly higher at N0 (39.23 g) than at N3 (35.24 g).

As for the genotypes, they showed different capacities for the expression of yield and its components (Table 11, Figure 18). The genotypes Megress, Massinissa and Waha gave the best yields with an average of 2396.29, 2321.75 and 2312.50 kg ha-1, respectively. The highest TGW was obtained by Megress, Massinissa and MBB with an average of 42.5 g, 37.77 g and 37.19 g (Table 11).

The best harvest index was obtained by Megress, Waha and GTAdur with an average of 37.76%, 37.22% and 36.42%. However, Bousselam showed the highest number of spikes m-² with an average of 290.74 spikes m-².

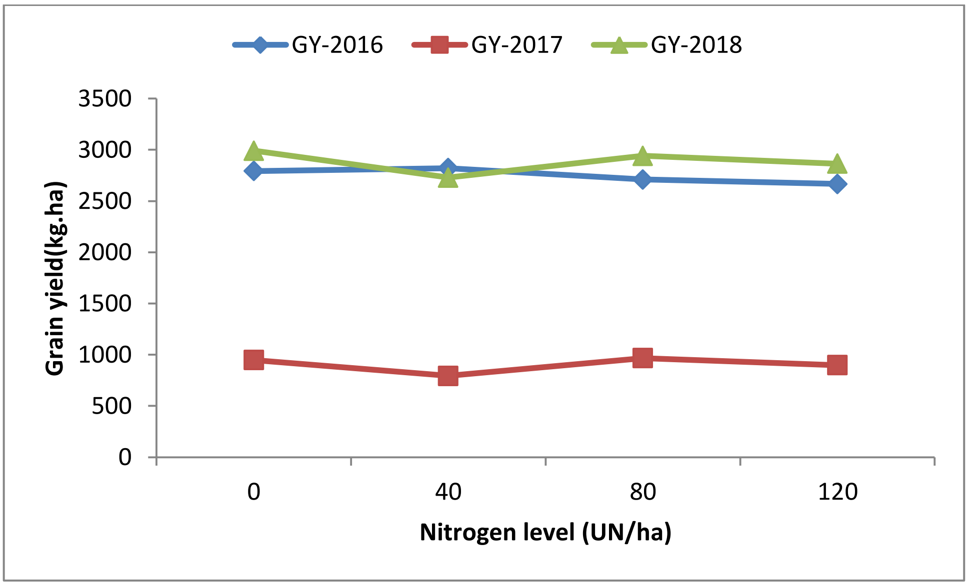


Figure 17 . Nitrogen effect on grain yield in the three growing seasons (2016/2017/2018)

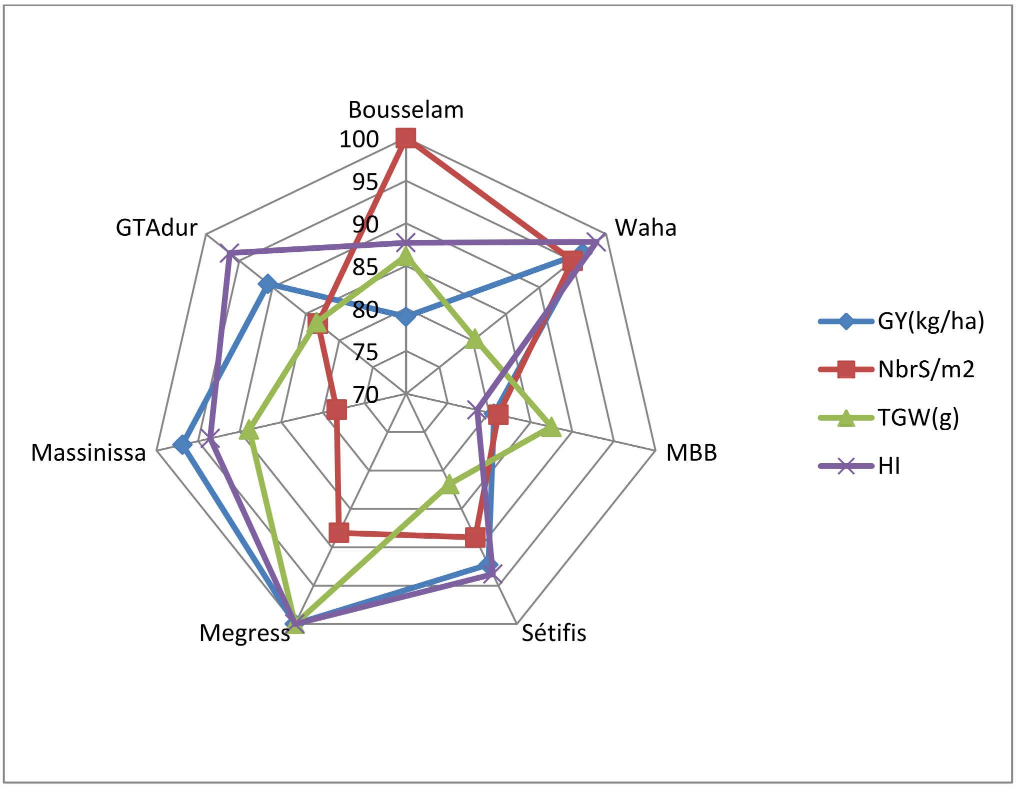


Figure 18 . Nitrogen effect on genotype grain yield performance

3.3. MARGINAL NET RETURN (MNR)

The marginal net return (MNR) of N fertilization significantly differed between years and genotypes (Table 11); the highest value of MNR was obtained in the wet year of experimentation (2017/18) with an average of 782.62 € t−1, and the lowest value was obtained in the dry year (2016/17), with a reduction of 71% in the profit. Whereas the N effect was significant; moreover, N produced an economic reduction of about 12% from N0 to N120 (from 628.99 to 550.73 € t−1).

For the genotype effect, the genotypes studied showed different values of MNR, a cheaper management was shown for the genotypes respectively: Megress (646.66), Massinissa (625.77€ t−1), Waha (623.17€ t−1), Sétifis (594.75€ t−1), GTAdur (584.11€ t−1), MBB (516.24 € t−1), Bousselam (505.73€ t−1).

3. 4. DISCUSSION

In the present study, in an Algerian semiarid environment, the response of wheat grain yield to N level was not significant and very dependent on the yearly weather conditions and on the cultivated genotypes. The experiments were performed in a semi-arid region with low rainfall below 500 mm per year (over 21 years, the average annual rainfall was 359.3 mm).

The total rainfall in the three experimental years was 382.3 mm, 195.12 mm, and 440.7 mm, in 2015/16, 2016/17, and 2017/18, respectively. Therefore, it is evident that 2016/17 was a much drier year; in addition, in that season, the rain was poorly distributed throughout the cycle: an excess of rains occurred during the vegetative phase, followed by a severe deficit at the flowering stage and during grain filling. Rainfall between emergence and anthesis (Jan–April) varied more appreciably between the years of cultivation, totaling 160.4 mm, 66.62 mm, and 208.8 mm in 2015/16, 2016/17, and 2017/18, respectively. Rainfall during grain filling was also different between the years, although less drastically, 110, 64.7, and 91 mm from the first to the third year. For both 2015/16 and 2017/18, rainfall in the period between emergence and anthesis and during grain filling was higher than the long-term average, while in the second year 2016/17 it was much lower than the long-term average. The mean monthly temperature was similar over the three years and similar to the long-term average, but wide fluctuations were observed, particularly in the last period of the growing season with temperatures lower than the long-term average in the first and last years, and higher in the second year .

Most likely the excess of rains during the vegetative phase (Jan–Feb) in the first year 2015/2016 coupled with increasing levels of N fertilization promoted overtillering and, as a result, an increase in total dry matter (8668.45 kg ha−1), with a reduced number of fertile spikes m−2 (262.79). These aspects most likely caused the reduction in the soil moisture during the grain filling period, and this exposed the wheat plants to water deficit, coupled with poor grain filling (TGW = 38.35 g), low grain yield (2748.01 kg ha−1), and low harvest index (31.78%). These effects of the driest year are evident when compared to the third cropping season 2017/18, which was characterized by a more adequate rainfall distribution during the vegetative phase, which assured a higher number of fertile spikes m−2 (317.34) and a higher harvest index (37.56%), with superior TGW (41.24 g) and GY (2881.34 kg ha1).

During the three years, for all genotypes, the average grain yield was rather stable, fluctuating only between 2100 and 2200 kg ha−1 at the different N levels, notwithstanding the significant variation in the fertilization amounts between treatments. Similar results were reported by (Lopez-Bellido et *al*., 2004), who showed, from a long termlong-term experiment, that the response of wheat to N fertilizer levels in drought years, with rainfall below 450 mm in the growing season, could be low or nonexistent. In contrary, (Souissi et *al*., 2020) showed a significant effect of N supply on grain yield under semi-arid conditions.

The results of the marginal net return showed that the N supply have a significant impact on it and produced a reduction of 12% in the farmers' income when passing from N0 to N120, in agreement with (Karrou, 1996).

On the other hand, in this study, there was a positive response of total dry matter at flowering to the increasing N. This positive effect was mainly due to the positive response of the number of tillers m−2 (DMS-F), whose consequence was a higher number of spikes m−2. This result can be explained by the fact that the water deficit and the high temperatures that occurred during the period of elaboration of the grain number (spike fertilization) and grain weight components were more limiting factors than the N availability; as a result, yields remained low in general. This result is in agreement with those of (Corbeels et *al.*, 1998; Panayotova et *al.*, 2017; Adeyemi et *al.*, 2020; Pampana et Mariotti, 2021) who showed that the climatic conditions (temperatures and rainfalls) during the vegetative season played a key role in grain production.

However, for the genotypic variability, our results showed different responses. The genotypes, Megress, Massinissa, Waha, Sétifis and GTAdur, expressed better performances in terms of grain yield and they maintained such performances throughout the years and under different conditions of N availability. We can explain this result as these genotypes are more modern and more productive than the old ones (Bousselam and MBB).

As a result, under semiarid conditions in Algeria, the water deficit and high temperatures during grain filling are more limiting factors than N availability; moreover, the modern genotypes respond better to N fertilization than the old genotypes, .which is in agreement with the proposal of (Gagliardi et *al.*, 2020) to limiting N inputs by adopting genotypes capable to optimize better the N fertilization.

4. NITROGEN UPTAKE AND N DISTRIBUTION

Nitrogen is one of the main factors limiting durum wheat production. The mean values of N uptake by grain (NG), Total nitrogen uptake at maturity (NM) and Nitrogen Harvest Index (NHI) and their statistical significances are mentioned in table 12.

Table 12. Means and ANOVA results of NG, NM and NHI.

		NG	**NM**	**NHI**
Years effect (Y)	2015/16	60.37	90.99	0.66
	2016/17	24.92	33.62	0.73
	2017/18	78.32	110.10	0.70
Test F	**P**	**<.0001*****	**<.0001*****	**<.0001*****
Nitrogen level effect (N)	0	46.12	64.68	0.71
	40	51.57	72.01	0.71
	80	59.51	85.17	0.70
	120	60.96	91.08	0.67
Test F	**P**	**<.0001*****	**<.0001*****	**0.0221***
Genotype effect (G)	Bousselam	50.05	73.96	0.68
	MBB	52.00	78.18	0.66
	Megress	61.78	85.35	0.73
	GTAdur	54.32	75.44	0.72
Test F	**P**	**0.0016****	**0.0216***	**<.0001*****
Y*N	**P**	0.0003**	<.0001***	0.1353NS
Y*G	**P**	0.0081**	0.0682NS	0.0465*
G*N	**P**	0.0282*	0.0167*	0.6545NS
Y*G*N	**P**	0.2388NS	0.3935NS	0.3526NS
	Means	**54.54**	**78.24**	**0.70**
	CV%	24.07	21.10	8.94

NG= N uptake by grain (kg N ha^{-1}), **NM=** Total nitrogen uptake at maturity (kg N ha^{-1}), **NHI=** Nitrogen Harvest Index (%), **NS=** no significant value, ***=** significant value at P <0.05, ****=** significant value at P <0.01, *****=** significant value at P <0.001, **CV%=** Coefficient of variation.

4.1. TOTAL NITROGEN UPTAKE AT MATURITY NM

Total N uptake at maturity (NM) significantly differed between years, N level and genotypes. Moreover, there were significant interactions between N*G and N*Y for NM (Table 12). The NM was proportional to weather conditions of the cropping year; it was 110.10 kg N ha-1 in the wet year (2017/18) and much lower in dry year: 33.62 kg N ha-1 in

2016/17, compared to 90.99 kg N ha-1 in 2015/16. In the three years, the NM significantly varied with N level. It was always significantly greater when N fertilizer was applied compared to the unfertilized condition, and it increased from 64.68 kg N ha-1 at N0 to 91.08 kg N ha-1 at N3 (Figure 19). The studied genotypes expressed different capacities to uptake N; Megress expressed the best capacity with an average value of 85.35 kg N ha-1, followed by MBB, GTAdur and Bousselam with an average value of 78.18, 75.44 and 73.96 kg N ha-1, respectively (Figure 19 and 21).

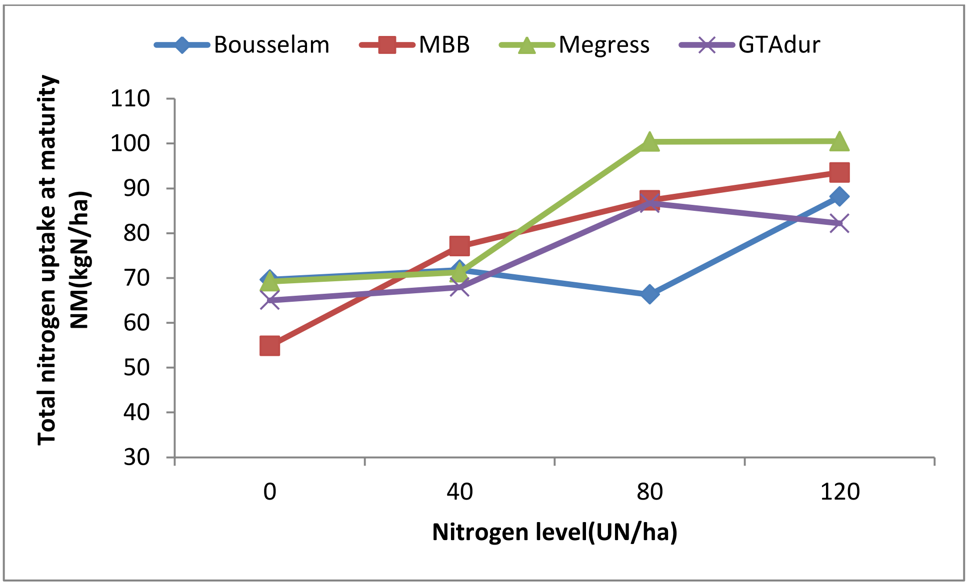


Figure 19. Total nitrogen uptake by whole plant as affected by nitrogen level

4.2. NITROGEN UPTAKE BY GRAIN NG

Nitrogen uptake by grain (NG) depends on N remobilization from vegetative organs and N uptake after flowering (Jeuffroy and Oury, 2012). Our results showed that growing season, wheat genotype and N level significantly affected the N uptake by grain (NG).

Moreover, there were significant interactions between N*G, N*Y and G*Y (Table 12). The NG was higher in the wet year 2017/18 (78.32 kg N ha-1) and much lower during the dry year 2016/17 (24.92 kg N ha-1) compared to 2015/16 (60.37 kg N ha-1). The NG was much affected by year, as by the significant interaction N*Y (Table 12). In the three years, NG was positively affected by the N increase. It was significantly higher at N3 compared to unfertilized conditions (N0) with an increase of 24.35% (Figure 20). The studied genotypes expressed different capacities to uptake N by the grains. Megress expressed the best capacities with an average value of 61.78 kg N ha-1, followed by GTAdur, MBB and Bousselam with respective values of 54.32, 52.00 and 50.05 kg Nha-1 (Figure 21).

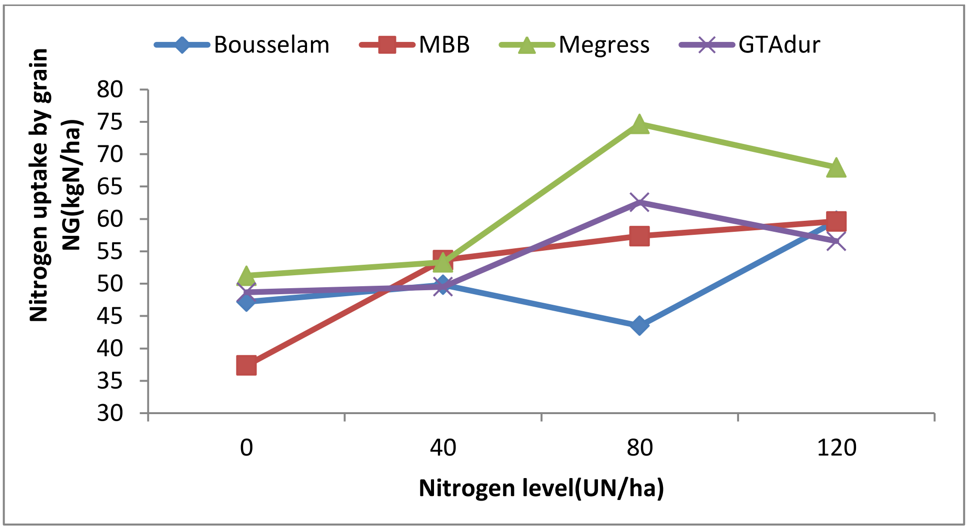


Figure 20. Total nitrogen uptake by grain NG as affected by nitrogen level

4.3. NITROGEN HARVEST INDEX NHI

Nitrogen harvest index (NHI) represents the crop's ability in partitioning the total N uptake between the different plant organs (Albrizio et al., 2010). The results showed that NHI varied significantly between years, N level and genotypes (Table 12). The highest NHI was obtained in the dry year 2016/17 with an average value of 0.66, 0.73 and 0.70 recorded in 2015/16, 2016/17 and 2017/18, respectively. However, increasing N level, NHI overall decreased from 0.71 at N0 to 0.67 at N3. As for the role of genotypes, NHI differed in the range between 0.73 (Megress), 0.72 (GTAdur), 0.68 (Bousselam) and 0.66 (MBB).

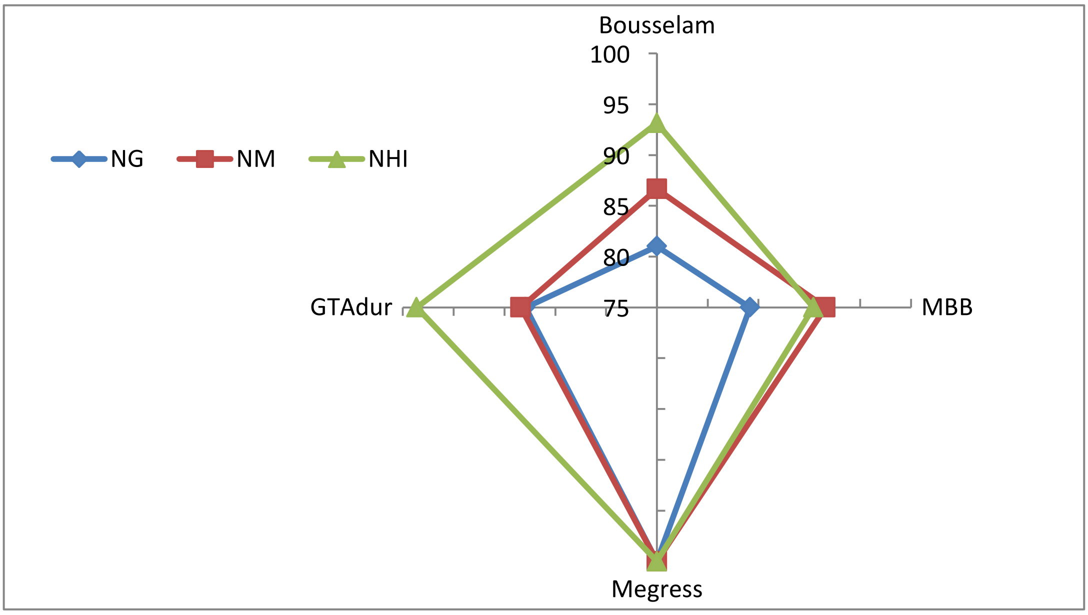


Figure 21. Genotype performance to uptake nitrogen(NG= N uptake by grain (kg N ha^{-1}), NM= Total nitrogen uptake at maturity (kg N ha^{-1}), NHI = Nitrogen Harvest Index (%)).

4.4. DISCUSSION

The total nitrogen uptake at maturity NM and by grain NG was significantly related to weather conditions. They were higher in the year with higher rainfall (440.7 mm) than in the other two years (382.3 and 195.12 mm, respectively). These results were in agreement with those of (Albrizio et *al*., 2010), who reported that N concentration in the grain was affected by N fertilization but with a different trend as a function of weather conditions. This was also confirmed by the significant interaction between year and nitrogen. For the N effect, both NM and NG increased significantly with N increasing, confirmed also in semiarid environments by the results of many authors (Lopez-Bellido et *al*., 2004; Gagliardi et *al*., 2020; Adeyemi et *al*., 2020), who reported that increasing N fertilizer levels prompted increased N uptake by grain and by the whole plant at maturity.

The total N uptake by grain NG over the whole study increased by an average of 24.34% from N0 to N3. The mean grain N content was 54.54 kg N ha−1, and it constituted 69.70% of total N uptake at maturity. These results also showed that the quantities of N uptake by the whole plant at maturity (NM) were greater than the quantities of N supply, whatever the initial richness of the soil in this element, except at the last N level, N3, where the N uptakes calculated by the N content were lower than the quantities of N supply. Therefore, under high fertilizer supply (N3) conditions, the quantities supplied by the soil were practically null, and we can hypothesize a significant loss of the unused N through the soil. In the present study, the studied genotypes showed different capacities to uptake and remobilize N. The more modern genotypes (Megress and GTAdur) expressed the best capacities with an average of 85.35 and 75.44 kg N ha−1 for NM and 61.78 and 54.32 kg N ha−1 for NG, respectively. Moreover, the two genotypes showed a higher ability in partitioning the total N uptake between different plant organs (NHI) in the studied environment, with an average value of 0.73 recorded by Megress and 0.72 by GTAdur. As expected, the modern genotypes were more efficient than the old genotypes for many traits.

NHI was significantly affected by year; the highest values were recorded in 2017, the dry year, with the lowest biomass (straw and grain); in contrast, NHI decreased along with the increasing N level, which is in agreement with the results of (Albrizio et *al*., 2010).

As a result, under semiarid conditions in Algeria, the N uptakes by the grain and by the whole plant are improved by the N supply with a different trend as a function of weather conditions.

5. NITROGEN USE EFFICIENCY NUE AND ITS COMPONENTS

Nitrogen is supply in very large and increasing quantities in durum wheat production. However, its use efficiency in cereal is low (Raun and Johnson, 1999). The mean values of Nitrogen use efficiency (NUE) and its components: Nitrogen uptake efficiency (NUpE) and Nitrogen utilization efficiency (NUtE) and their statistical significances are mentioned in table 13.

Table 13. Means and ANOVA results of NUE and its components.

		NUE	**NUpE**	**NUtE**
Years effect (Y)	2015/16	19.87	0.74	26.11
	2016/17	7.95	0.29	27.34
	2017/18	16.50	0.68	24.07
Test F	**P**	**<.0001*****	**<.0001*****	**0.0042****
Nitrogen level effect (N)	0	/	/	/
	40	19.06	0.66	28.22
	80	14.35	0.57	25.30
	120	10.91	0.47	24.00
Test F	**P**	**<.0001*****	**<.0001*****	**0.0001****
Genotype effect (G)	Bousselam	12.67	0.50	24.73
	MBB	15.02	0.54	27.66
	Megress	14.89	0.62	23.41
	GTAdur	16.51	0.60	27.55
Test F	**P**	**0.0129***	**0.0024****	**0.0002****
Y*N	**P**	0.0157*	0.9928NS	0.0003**
Y*G	**P**	0.1050NS	0.0103*	0.6472NS
G*N	**P**	0.0924NS	0.1114NS	0.8552NS
Y*G*N	**P**	0.5432NS	0.4855NS	0.7195NS
	Means	**14.77**	**0.57**	**25.84**
	CV%	28.30	22.05	15.72

NUE= Nitrogen use efficiency (kg kg^{-1}), **NUpE=** Nitrogen uptake efficiency (kg kg^{-1}), **NUtE=** Nitrogen utilization efficiency (kg kg^{-1}), **NS=** no significant value, ***=** significant value at P <0.05, ****=** significant value at P <0.01, *****=** significant value at P <0.001, **CV%=** Coefficient of variation.

5.1. NITROGEN USE EFFICIENCY NUE

NUE is expressed as the kg of yield harvested per kg of N fertilizer applied. According to (Ladha et al., 2005; Masclaux-Daubresse et *al*., 2010), it is the efficiency ratio of output (total plant N, grain N, biomass yield, grain yield) to input (total N, soil N or N-fertilizer applied). The NUE was mostly influenced by the cropping year (Table 13, Figure 25). The average NUE was 19.87, 7.95 and 16.50 (kg kg-1) in 2015/16, 2016/17 and 2017/18, respectively. As expected, NUE was negatively affected by the increase of N fertilization rate (Table 13, Figure 22). It was significantly higher at N1 (19.06 kg kg-1) than at N2 (14.35 kg kg-1) and at N3 (10.91 kg kg-1). In the present study, NUE values at N3 were 43% lower than those obtained at N1. However, the decrease was less marked in 2015/16 (52%), vs. 55% in 2016/17 and 65% in 2017/18, as shown by the trend in the interaction N*Y. As for genotypes, the results showed that they expressed different abilities in NUE, the genotype GTAdur being more N efficient, with an average of 16.51 kg kg-1, than MBB (15.02 kg kg-1), Megress (14.89 kg kg-1) and Bousselam (12.67 kg kg-1) (Figure 26).

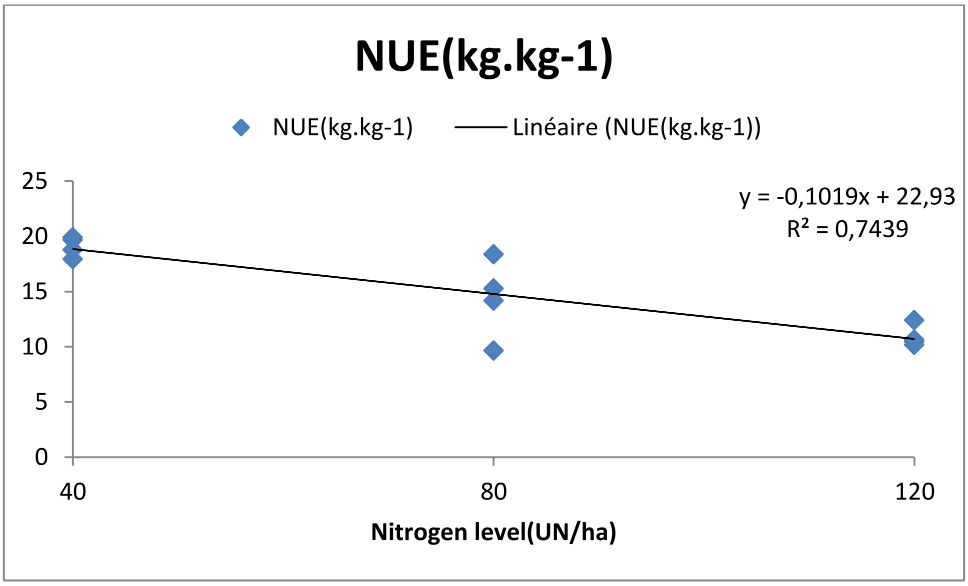


Figure 22. NUE as affected by nitrogen level and by growing season

5.2. NITROGEN UPTAKE EFFICIENCY NUPE

NUpE is the ability of the plant to remove N (as ammonium or nitrate ions) from the soil. According to Hawkesford (2017), it widely depends on the cropping systems and N application strategies (timing, splitting and forms of N used). Results showed that wheat NUpE differed significantly between years, nitrogen levels and genotypes. Moreover, there was a significant interaction Y*G (Table 13). As the average of N levels and genotypes, NUpE was 0.74 kg kg-1 in the less rainy first year 2015/16, vs. 0.68 kg kg-1 in the rainiest third year 2017/18 and showed a very low value in the dry year 2016/17 (0.29 kg kg-1) (Table 13, Figure 25). However, NUpE decreased with the increase of N level (Table 12, Figure 23). It was 0.66, 0.57 and 0.47 kg kg-1 for the N1, N2 and N3, respectively. In three years, the tall genotypes MBB and Megresse had higher NUpE values (0.54 and 0.62 kg kg-1, respectively) than the short ones Bousselam and GTAdur (0.50 and 0.60 kg kg-1, respectively) (Figure 26).

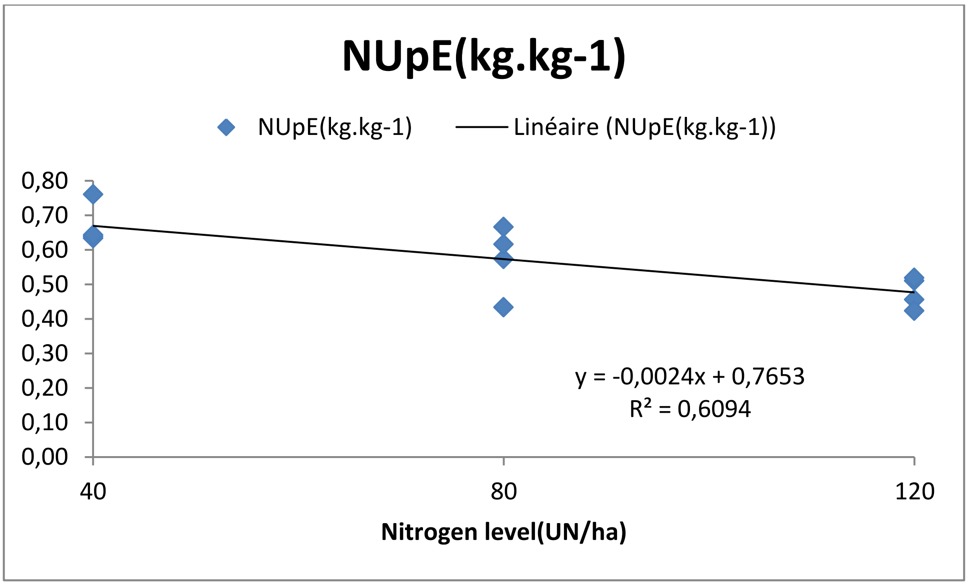


Figure 23. NUpE as affected by nitrogen level and by growing season

5.3. NITROGEN UTILIZATION EFFICIENCY NUTE

NUtE is a parameter expressing the ability of the plant to translate the uptake N into economic yield (grains) (Delogu et *al*., 1998b). Results showed that wheat NUtE differed significantly between years, N levels and genotypes. Moreover, there was a significant interaction Y*N (Table 13). NUtE was highly influenced by the cropping year, most likely by the yearly amount of rains; the highest value was registered in the dry year 2016/17 with an average value of 27.34 kg kg-1; the values of 26.11 kg kg-1 and 24.07 kg kg-1 were in turn registered in the year 2015/16 and in the more rainy 2017/18, respectively (Table 13, Figure 25).. Moreover, the results showed that NUtE decreased with the increasing N level (Table 13, Figure 24), with values of 28.22, 25.30 and 24.00 kg kg-1 at N1, N2 and N3, respectively. In three years, the results altogether showed that the genotypes expressed different abilities in NUtE; with MBB and GTAdur owning a more efficient translocation of N from the plant to the grain with an average value of 27.66 and 27.55 kg kg-1 respectively, than Bousselam and Megress, with value of 24.73 and 23.41 kg kg-1, respectively (Figure 26).

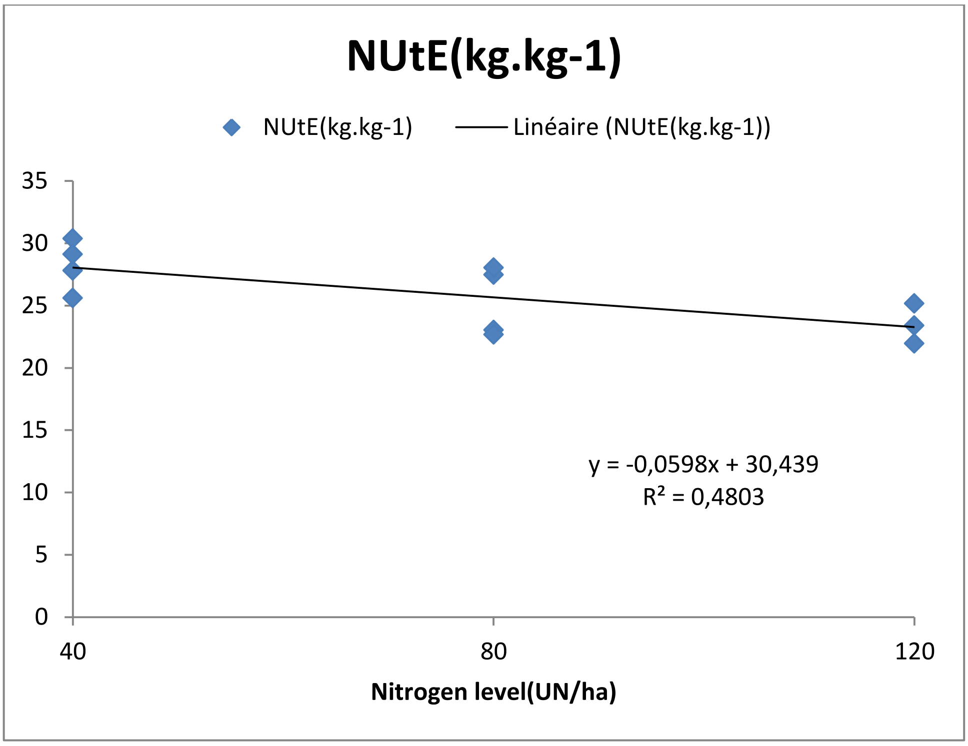


Figure 24. NUtE as affected by nitrogen level and by growing season

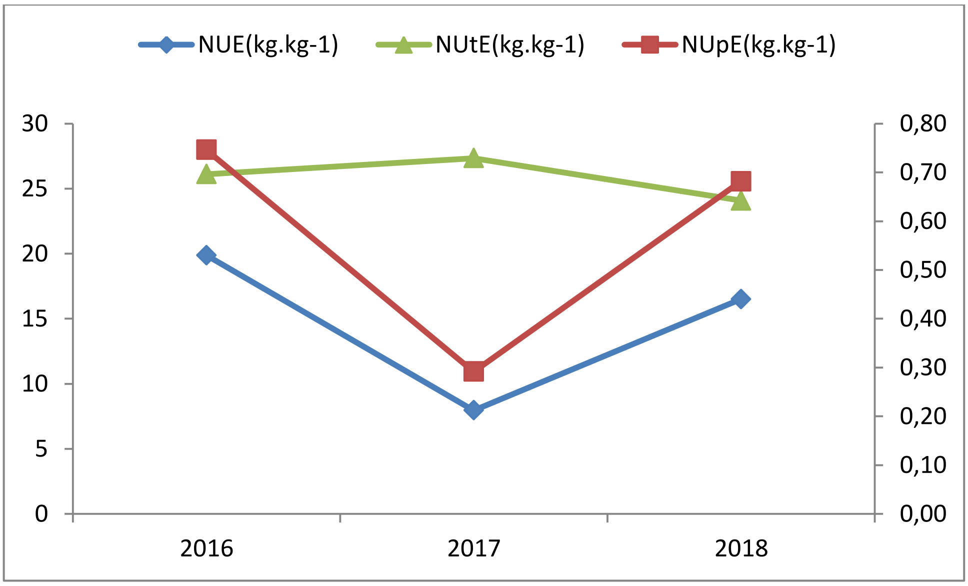


Figure 25. NUE and its components in three growing season (2016/2017/2018)

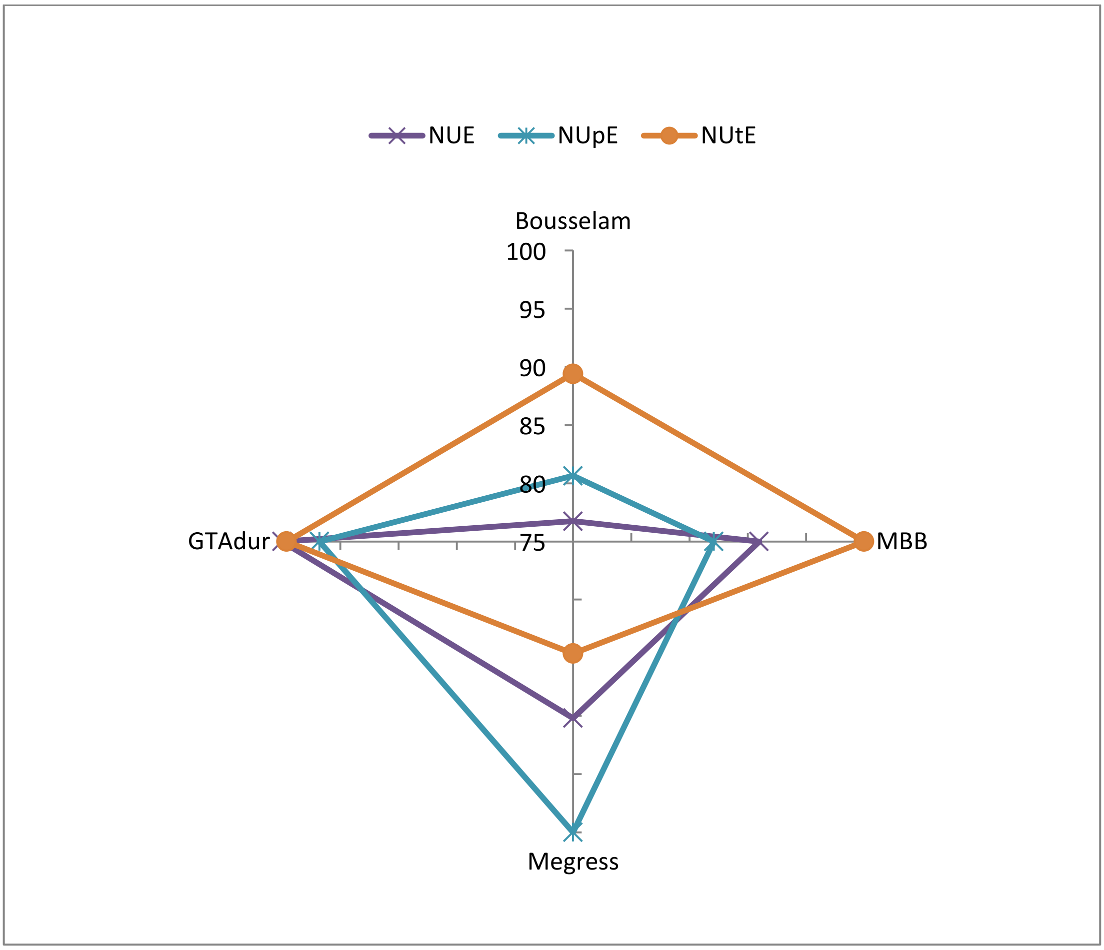


Figure 26. Genotypes performance for NUE and its components

5.4. CORRELATIONS BETWEEN NUE AND ITS COMPONENTS WITH OTHER TRAITS

To understand the relationships between GY, yield components and total dry matter, a correlation analyses was performed among all these traits (Table 14). Results indicated that the GY was significantly and positively correlated to total dry matter accumulated at flowering DMF (r=0.61***) and maturity DMM (r=0.89***), NbrS/m² (r=0.45***), thousand grain weight TGW (r=0.69***) and HI (r=0.17*). The harvest index (HI) showed negative and significant correlations with the DMF (r =-0.34 ***) and DMM (r = -0.24**) and NbrS/m2 (r= -0.23**). However, HI was correlated significantly and positively with TGW (r =0.28**).

Regarding NUE determination, the correlation analyses indicated that significant correlations were found. NG was significantly and positively correlated to DMF (r=0.51***), DMM (r=0.80***), GY (0,90***), NbrG/m² (r=0.90***), NbrS/m² (r=0.58***) and TGW (r=0.54***). The NM significantly and positively to DMF (r=0.59***), DMM (r=0.85***), NG (r=0,97***), GY (0,86***), NbrG/m² (r=0.88***), NbrS/m² (r=0.64***) and TGW(r=0.48***).

NHI showed negative and significant correlations with DMF (r =-0.39 ***), DMM (r = -0.25**) and NbrS/m² (r=-0,28**). It was also related significantly and positively with TGW (r =0.26**). The NUE was significantly and positively related to DMF (r=0.53***), DMM (r=0.71***), GY (0,79***), NbrG/m² (r=0.75***), NbrS/m² (r=0.21*), TGW(r=0.61***), NG(r=0,64***) andNM (r=0,59***). The NUpE was significantly and positively related to DMF (r=0.65***), DMM (r=0.84***), GY (0,84***), NbrG/m²(r=0.81***), NbrS/m² (r=0.40***), TGW(r=0.60***), NG(r=0,78***), NM(r=0,79***) and to NUE (r=0,90***). The NUtE was significantly and negatively related to NbrS/m² (r=-0.37***), TGW(r=-0.22*) and NM(r=-0,29**). It was however, related significantly and positively to HI (r=0.54***), NHI(r=0.75***) and NUE (r=0.35**).

To understand the relationships between NUE, yield and their components, correlation analysis was performed considering all recorded traits (Table 14). Results of correlations indicated that NUE was significantly and positively related with GY (0.79***), DMM (0.71***), NG (0.64***), TGW (0.61***), and NM (0.59***).

NUpE was significantly and positively related to GY (0.84***), DMM (0.84***), NM (0.79***), NG (0.78***), and TGW (0.60***).

NUtE was significantly and positively correlated to NHI (0.75***) and HI (0.54***); moreover, it was significantly and negatively related to NbrS m-² (-0.37***), NM (-0,29**), and TGW (-0.22*), respectively.

Table 14. Relationships between NUE and its components with dry matter, grain yield, and its components (In black are the positive correlations, while in red are the negative ones).

	DMF	DMM	GY	NbrS m^{-2}	TGW	HI	NG	NM	NHI	NUE	NUpE	NUtE
DMF	1											
DMM	0.78***	1										
GY	0.61***	0.89***	1									
NbrS m^{-2}	0.45***	0.54***	0.45***	1								
TGW	0.35***	0.57***	0.69***	0.26**	1							
HI	-0.34***	-0.24**	0.17*	-0.23**	0.28**	1						
NG	0.51***	0.80***	0.90***	0.58***	0.54***	0.15 NS	1					
NM	0.59***	0.85***	0.86***	0.64***	0.48***	0.01 NS	0.97***	1				
NHI	-0.39***	-0.25**	0.08 NS	-0.28**	0.26***	0.81***	0.03 NS	-0.16*	1			
NUE	0.53***	0.71***	0.79***	0.21*	0.61***	0.11 NS	0.64***	0.59***	0.16 NS	1		
NUpE	0.65***	0.84***	0.84***	0.40***	0.60***	-0.06 NS	0.78***	0.79***	-0.07 NS	0.90***	1	
NUtE	-0.16 NS	-0.13 NS	0.07 NS	-0.37***	-0.22*	0.54***	-0.14 NS	-0.29**	0.75***	0.35**	-0.025 NS	1

DMF= Total dry matter at flowering (kg ha^{-1}), **DMM=** Total dry matter at maturity (kg ha^{-1}), **GY=** Grain yield (kg ha^{-1}), **NbrS m^{-2}=** Number of spike m^{-2}, **TGW=** Thousand grain weight (g), **HI=** Harvest index (%), **NG=** N uptake by grain (kg N ha^{-1}), **NM=** Total nitrogen uptake at maturity (kg N ha^{-1}), **NHI=** Nitrogen Harvest Index (%), **NUE=** Nitrogen use efficiency (kg kg^{-1}), **NUpE=** Nitrogen uptake efficiency (kg kg^{-1}), **NUtE=** Nitrogen utilization efficiency (kg kg^{-1}).

5.5. DISCUSSION

For NUE, in general, our results indicated that NUE and its components (NupE and NUtE) were strongly affected by the climatic conditions each year and also by N in-creasing levels and genotypes. The response of NUE was dependent on the yearly climate, especially the rain distribution and amount during the vegetative phase of the growing cycle.

In the present study, the mean of NUE averaged through the three N levels was only 50% of the world average, about 14.77 kg kg−1. The lowest values of NUE and NUpE were recorded in the driest year 2016/17 (7.95 and 0.29 kg kg−1, respectively). On the other hand, the highest values (19.87 and 0.74 kg kg−1, respectively) were obtained in the first year (2015/16), which was characterized by more precipitation during the vegetative phase (Jan–Feb). In fact, there was a more favorable rain distribution throughout the cycle that allowed a higher accumulation of the total dry matter at maturity (DMM) vs. the other two years, and this assured high values of NUE. These results were confirmed by the high correlation between NUE and DMM (0.71 ***), which is in agreement with the results reported by (Ayadi et *al.*, 2014; Panayotova et *al.*, 2017). The highest value of NUtE was obtained in the driest year with 27.34 kg kg−1, which could be explained by the fact that the number of spikes m−2 and the total dry matter of straw at maturity were lower in that year, thus, increasing the ability of the plant to translate the N uptake to economic yield in the lower number of grains per unit area. As for the N effect on the efficiency parameters, the results showed that the NUE and its components NUpE and NUtE were negatively affected by the N increase. This can be expected with the increase in N availability, as similar results have been reported by many authors in different climates: temperate climate conditions, (Rahimizadeh et al., 2010; Gagliardi et al., 2020; Pampana and Mariotti, 2021)Mediterranean climate conditions (Giambalvo et *al.*, 2004, 2010; Albrizio et *al.*, 2010; Gagliardi et *al.*, 2020; Adeyemi et *al.*, 2020), and semiarid conditions as well (Karrou, 1996; Almaliev et *al.*, 2012; Ayadi et *al.*, 2014; Ierna et *al.*, 2016; Gagliardi et *al.*, 2020). In López-Bellido and coauthors, they reported that NUE values in bread wheat at a maximum N fertilizer level of 150 kg N ha−1 were 49% lower than those obtained at 0 kg N ha−1. In addition, (Barut et *al.*, 2015; Souissi et *al.*, 2020), reported that durum wheat grown under rainfed semiarid conditions was more efficient in water use and less efficient in N use.

In the present study, NUE values at maximum (N3) N fertilization (N3) of 120 kg N ha−1 were 43% lower than those obtained at N1 of 40 kg N ha−1. However, in (Ierna et *al.*, 2016), under rainfed semiarid conditions, the reduction was around 61%. This trend was explained by the same author, that the negative relationship between N fertilization rates and NUE is explained by the non-linear pattern of yield response to N. However López-Bellido and coauthors, explained this negative relationship by the fact that the grain yield rises less than the N supply in soil and fertilizer. In (Delogu et *al*., 1998b), they explained the decrease in NUtE by the fact that the increase in crop N uptake with rising fertilizer levels is greater than the increase in grain yield. As for the genotype behavior, MBB and GTAdur had the highest values of nUE and NUtE, while Megress and GTAdur had higher values of NUpE.

The relative contribution of both components NupE and NUtE to the variation of NUE was confirmed by the correlation results, where it was shown that the gain in NUE was more strongly associated with NUpE (0.90) than with NUtE (0.35), which is in agreement with the results obtained by (Rahimizadeh et al., 2010). Moreover, the present study showed that GY was dependent on NUpE (0.84 ***) and NUE (0.79 ***), which is in agreement with the results obtained by Raun and Johnson (1999).

As a result, under semiarid conditions in Algeria, the NUE was more affected by the climatic conditions of the year, especially the rainfall during the vegetative phase of the growing cycle. Moreover, NUE and its components NupE and NUtE were negatively affected by an N increase. The modern genotypes were more efficient than the old ones.

Our results fill the knowledge gap on NUE in durum wheat under semiarid conditions. However, looking ahead, it would be important to continue long-term experi-mentation with different sites and genotypes to make further innovations and improve N fertilization practices.

6. EFFECT OF WEATHER CONDITIONS ON GRAIN YIELD, NUE, AND THEIR COMPONENTS

In this analysis, every season and location was considered a separate environment, and the environment was presented by the variation of climatic or weather conditions: the total rainfall at the vegetative period (RVP), the total rainfall at the flowering and filling period (RFFP), and the mean temperature (MT) in each year.

6.1. EVALUATION OF NITROGEN LEVEL, GENOTYPE, AND ENVIRONMENTAL EFFECTS ON DRY MATTER ACCUMULATION, GRAIN YIELD, AND ITS COMPONENTS

The mean values of dry matter at maturity (DMM), grain yield (GY) and its components: Number of spike/m^2 (NbrS/m2), Thousand grain weight (TGWg), HI=Harvest index (%) were presented in the table 15 and their signification were presented in the table 16.

Table 15. The mean values of dry matter at maturity DMM, grain yield GY and its components.

Environment	N level	DM-M	GY	NbrS.m2	TGW	HI
E1	**0**	**8181±887**	**2681±306**	**217±36**	**44±4**	**33±4**
	40	**8346±1446**	**2646±250**	**244±29**	**41±4**	**32±4**
	80	**8771±1374**	**2618±746**	**261±17**	**38±5**	**30±7**
	120	**9063±1286**	**2514±539**	**304±54**	**35±3**	**28±4**
	Mean	8590	2615	256	39	31
E2	**0**	**2933±822**	**1092±324**	**194±40**	**34±5**	**37±2**
	40	**2315±399**	**790±181**	**180±12**	**33±5**	**34±5**
	80	**2443±669**	**967±356**	**177±38**	**34±4**	**39±6**
	120	**2475±279**	**886±165**	**196±6**	**31±6**	**35±4**
	Mean	2542	934	187	33	36
E3	**0**	**7578±864**	**2719±729**	**303±84**	**43±3**	**36±7**
	40	**7789±764**	**2681±306**	**325±71**	**42±2**	**34±4**
	80	**7778±1143**	**2786±612**	**337±44**	**40±2**	**36±4**
	120	**7689±707**	**2803±290**	**338±73**	**41±1**	**34±6**
	Mean	7708	2747	326	41	35
E4	**0**	**10516±1728**	**3371±301**	**259±27**	**39±3**	**33±3**
	40	**10018±3078**	**3509±1109**	**255±89**	**38±1**	**35±3**
	80	**10344±2654**	**3707±1214**	**265±68**	**36±2**	**36±6**
	120	**12853±1289**	**4191±534**	**317±22**	**39±2**	**33±3**
	Mean	10933	3695	274	38	34
	General mean	7443	2498	261	38	34

DMM: Dry matter at maturity (kg ha-1), GY: grain yield (kg ha-1), NbrS/m2: Number of spike/m^2, TGW: Thousand grain weight (g), HI=Harvest index (%).

Table 16. Analysis of covariance for dry matter at maturity DMM, grain yield GY and its components.

	DMM	GY	NbrS.m2	TGW	HI
Genotype G	0,056.	0,005**	0,000***	0,000***	0,000***
Nitrogen level N	0,004**	0,336	0,000***	0,000***	0,024*
RVP	0,000***	0,000***	0,000***	0,000***	0,844
RFFP	0,000***	0,000***	0,922	0,000***	0,000***
MT	0,001**	0,000***	0,000***	0,109	0,000***
G*N	0,000***	0,000***	0,001**	0,302	0,364
G*RVP	0,000***	0,000***	0,076.	0,000***	0,115
G*RFFP	0,002**	0,023*	0,011*	0,018*	0,268
G*MT	0,006**	0,001***	0,000***	0,000***	0,019*
N*RVP	0,000***	0,003**	0,637	0,000***	0,262
N*RFFP	0,639	0,525	0,055.	0,000***	0,027*
N*MT	0,689	0,143	0,405	0,000***	0,116
G*N*RVP	0,000***	0,000***	0,000***	0,666	0,620
G*N*RFFP	0,848	0,555	0,119	0,062.	0,350
G*N*MT	0,431	0,288	0,021*	0,106	0,311

DMM: Dry matter at maturity, GY: grain yield, NbrS/m2: Number of spike/m², TGW: Thousand grain weight, HI=Harvest index, RVP: the total rainfall at vegetative period, RFFP: the total rainfall at flowering and filling period and MT: the mean temperature. **NS=** no significant value, ***=** significant value at P <0.05, ****=** significant value at P <0.01, *****=** significant value at P <0.001, **CV%=** Coefficient of variation.

6.1.1. Dry matter at maturity DMM

The analysis of covariance indicated a very highly and highly significant effect of all factors, except for genotype effect G (Table 15). The effect of total rainfall at vegetative period (RVP), total rainfall at flowering and filling period (RFFP) and the mean temperature (MT) were very highly and highly significant on total dry matter accumulated at maturity DMM (Table 16). The mean of DMM of all genotypes and all N level combined was different between environments, it was 10933 kg ha-1, 8590 kg ha-1, 7708 kg ha-1 and 2542 kg ha-1 respectively in the fourth environment E4, first environment E1, third environment E3 and second environment E2 (Table 15).

The effect of nitrogen level was highly significant on total dry matter accumulated at maturity DMM (Table 16, Figure 27). The positive response of DMM to nitrogen level increasing was very illustrated in the first and fourth environments E1 (R2=0,97), E4(R2=0,53) than the two others environments E2(R2=0,35), E3(R2=0,18) (Figure 28).

6.1.2. Grain yield and its components

The analysis of covariance ANCOVA showed a very highly and highly significant effect of all factors, except for N level effect N on grain yield, for its components NbrS/m2, TGW and HI, the ANCOVA analysis showed a very highly significant effect of all factors, except for total rainfall at flowering and filling period (RFFP) on NbrS/m2, the mean temperature (MT) on TGW and the total rainfall at vegetative period (RVP) on HI (Table 16).

The effect of environmental conditions, the total rainfall at vegetative period (RVP), total rainfall at flowering and filling period (RFFP) and the mean temperature (MT) were very highly significant on grain yield (Table 16). The mean value of grain yield of all genotypes and all N level combined was similar in the environments E1 (2615 kg ha-1) and E3 (2747 kg ha-1) and significantly lower in E2 (934 kg ha-1) and very higher in E4 (3695kg ha-1). For the NbrS/m2, the mean value was significantly different between environments: 256, 187,326 and 274 spikes/m2 respectively in E1, E2, E3 and E4. TGW was also significantly different between environments: 39, 33, 41 and 38 g respectively in E1, E2, E3 and E4.

The response of grain yield to N level increasing was not significant, however the response of NbrS/m2 and TGW were positively and negatively significant to N increasing (Table 15 and 16).

For the genotypes, they showed significant different capacities for the expression of yield and its components (Table 16, Figure 29). The genotypes GTAdur and Megress gave the best yields with averages of 2630 kg ha-1 and 2611 kg ha-1, respectively. The high TGW was obtained by Megress with an average of 41g, and also the best distribution of dry matter between grain and straw with a high HI of 37 %. However, Bousselam showed the high number of spikes/m² with an average of 291 spikes/m².

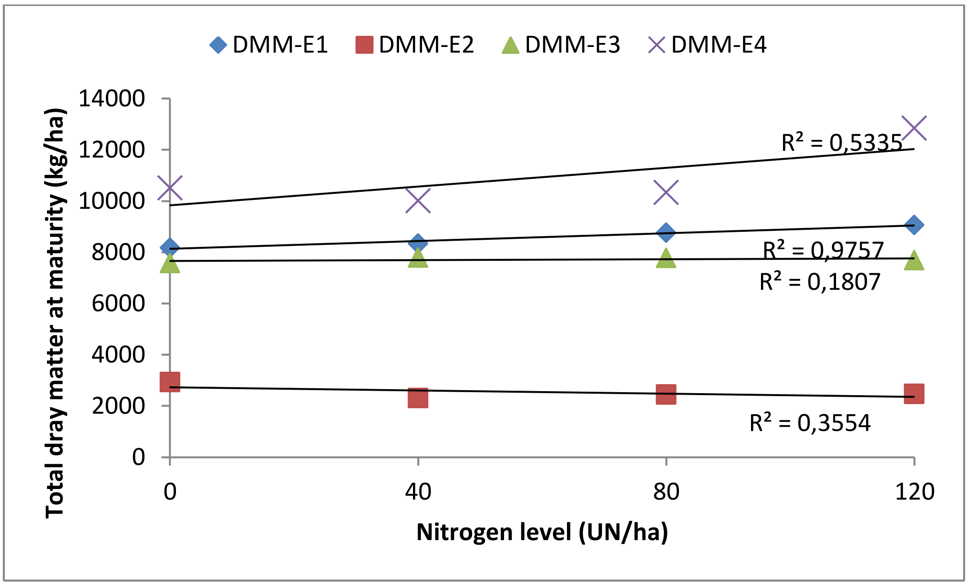


Figure 27. Nitrogen effect on total dry matter accumulated at maturity in the four environments.

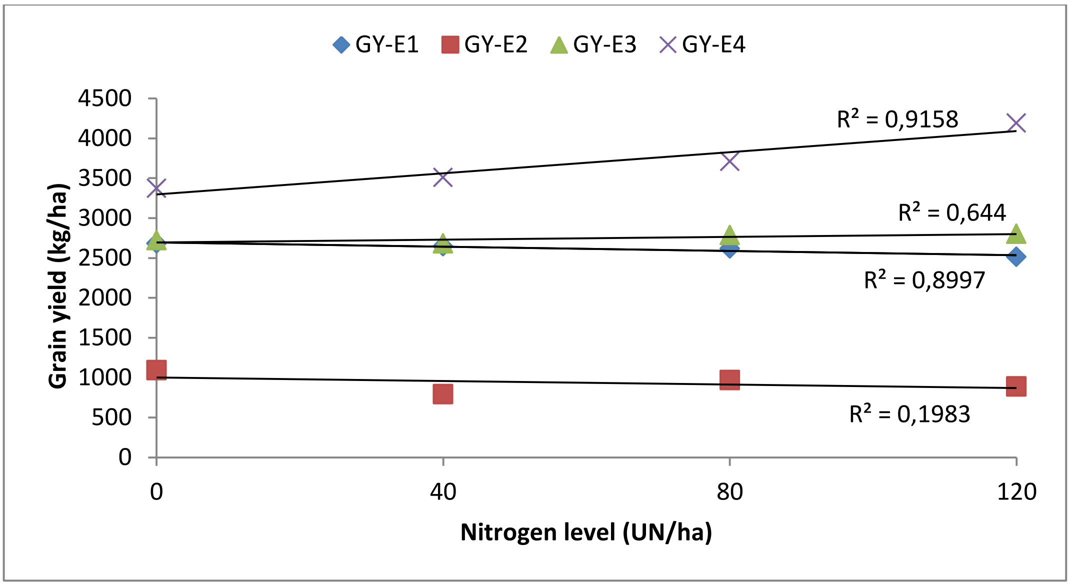


Figure 28. Nitrogen effect on grain yield in the four environments.

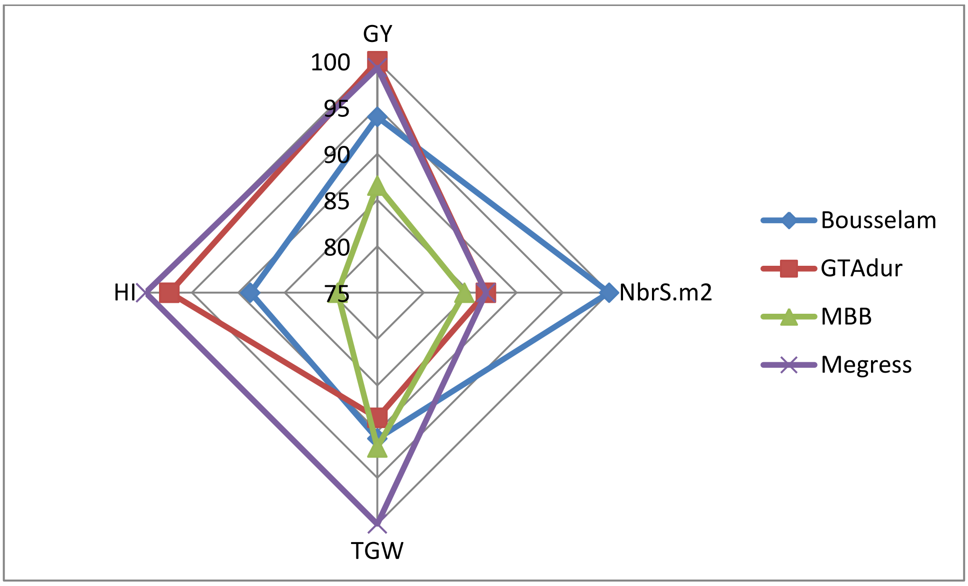


Figure 29. Genotypic performance of grain yield and its components.

6.1.3. ANALYSIS OF INTERACTIONS FOR DMM, GY AND ITS COMPONENTS

The analysis of interaction is more interesting, in these cases, than that of the mean effects. Indeed, a significant interaction suggests that the recommendations, in terms of nitrogen level to apply, or genotypes to adopt, are to be made per environment and not on average of the four environments.

A. Genotypes x N level interaction (G*N)

Interaction between genotypes and N level was significant for DMM, GY and NbrS.m2 (Table 16), Figure 30 show there was crossover of the regression lines. The nature of the interaction was explained by differences in response of genotypes to N levels.

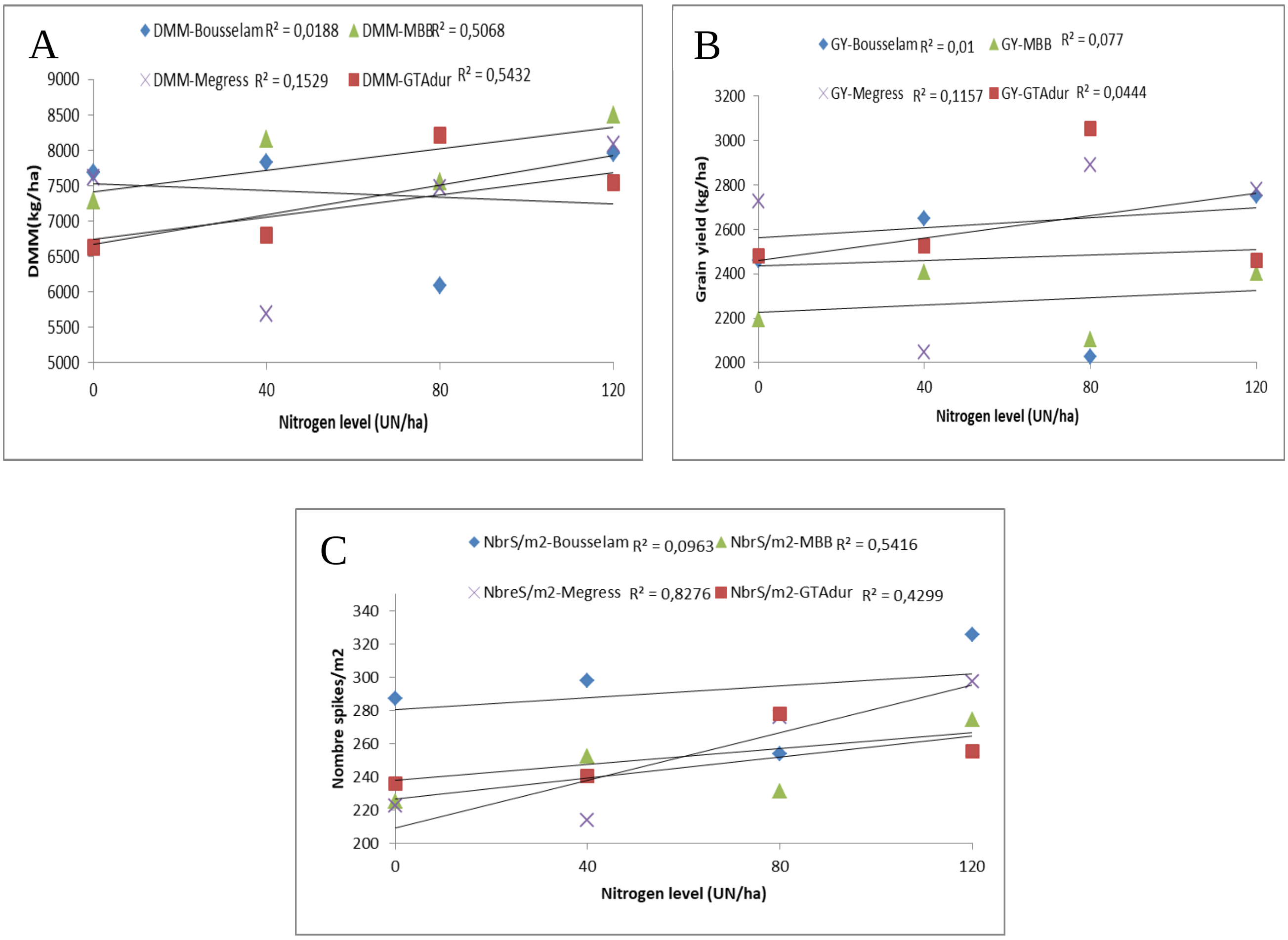


Figure 30. DMM (A), GY (B) and NbS.m2 (C) of 4 genotypes across under the 4 N levels.

B. Genotypes x Environment interaction (G*RVP/ G*RFFP/ G*MT)

Interaction between genotypes and the total rainfall at vegetative period (G*RVP) was significant for all parameters DMM, GY and TGW except for NbrS.m2 and HI (Table 16). Interaction between genotypes and total rainfall at flowering and filling period (G*RFFP) was significant for all parameters DMM, GY NbrS.m2 and TGW except for HI (Table 16). Interaction between genotypes and the mean temperature (G*MT) was significant for all parameters studied DMM, GY, NbrS.m2 TGW and HI (Table 16). These interactions were explained by differences in response of genotypes in different environments (Figure 31).

The ANCOVA analysis showed that the G*RVP and G*MT were very highly significant on grain yield (Table 16).

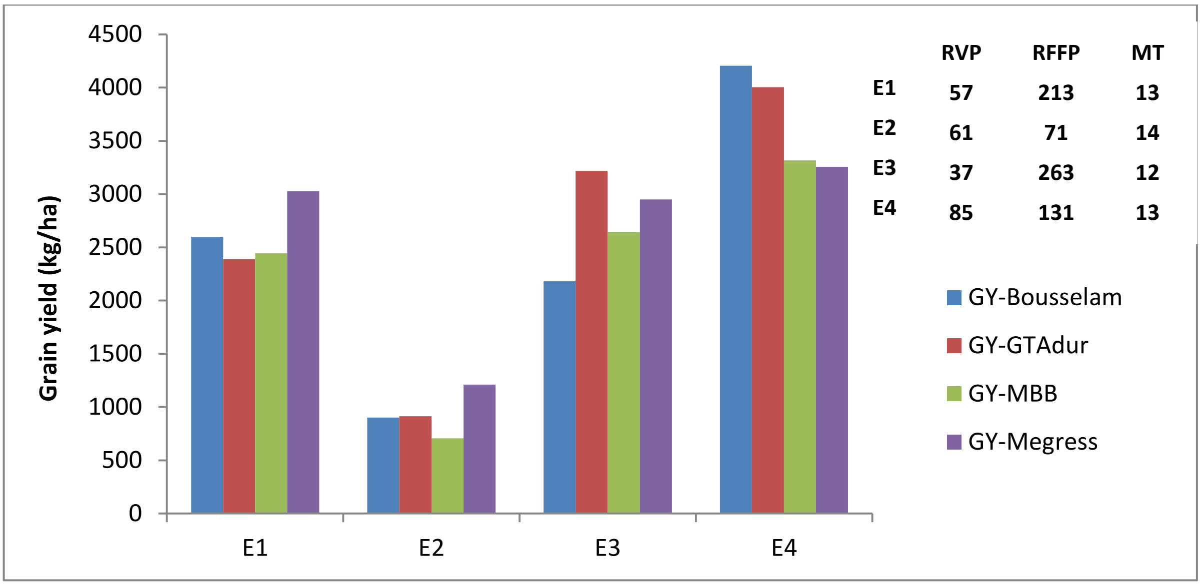


Figure 31. The variation of grain yield in the different environments studied (G* Environment interaction)

C. Nitrogen level N x Environment interaction (N*RVP/ N*RFFP/N*MT)

Interaction between nitrogen level and the total rainfall at vegetative period (N*RVP) was significant for all parameters DMM, GY and TGW except for NbrS.m2 and HI (Table 15). Interaction between nitrogen level and total rainfall at flowering and filling period (N*RFFP) was nit significant for all parameters DMM, GY NbrS.m2 except for TGW and HI (Table 16). Interaction between nitrogen level and the mean temperature (N*MT) was not significant for all parameters studied DMM, GY, NbrS.m2 and HI except for TGW (Table 16). The nature of the interaction was explained by differences in response of genotypes to N levels between environments.

The ANCOVA analysis showed that the N*RVP was highly significant on GY and the TGW. However N*RFFP and N*MT were very highly significant on TGW (Table 16).

6.2. EVALUATION OF NITROGEN LEVEL, GENOTYPE AND ENVIRONMENT EFFECTS ON NM, NUE AND ITS COMPONENTS : NUPE AND NUTE.

The mean values of total nitrogen uptake at maturity (NM), Nitrogen use efficiency (NUE) and its components: Nitrogen uptake efficiency (NUpE) and Nitrogen utilization efficiency (NUtE) were presented in the table 17 and their signification were presented in the table 18.

Table 17 . The mean values of NM, NUE and its components: NUpE and NUtE.

Environment	N level	NM	NUE	NUpE	NUtE
2016	40	83,45±10,86	26,79±1,96	0,84±0,07	31,89±3,02
2016	80	104,91±15,50	18,85±5,91	0,75±0,13	24,67±3,93
2016	120	115,99±22,42	13,98±3,06	0,64±0,12	21,77±1,91
	Mean	**101,45**	**19,87**	**0,75**	**26,11**
2017	40	29,57±5,12	10,10±2,16	0,38±0,08	26,71±3,21
2017	80	34,73±10,99	8,17±2,85	0,29±0,09	27,43±3,68
2017	120	31,56±3,65	5,61±0,94	0,20±0,02	27,88±2,10
	Mean	**31,95**	**7,96**	**0,29**	**27,34**
2018	40	103,03±10,49	20,30±3,71	0,78±0,17	26,06±2,30
2018	80	115,88±19,67	16,05±3,23	0,67±0,13	23,82±2,16
2018	120	125,71±7,65	13,15±1,16	0,59±0,05	22,35±1,51
	Mean	**114,87**	**16,50**	**0,68**	**24,08**
2019	40	116,55±35,61	24,07±8,96	0,81±0,32	30,79±0,71
2019	80	118,19±36,48	20,12±8,61	0,64±0,26	31,33±1,66
2019	120	143,12±13,88	18,21±2,63	0,62±0,06	29,10±1,20
	Mean	**125,95**	**20,80**	**0,69**	**30,41**
	General mean	**93,56**	**16,28**	**0,60**	**26,98**

NM: Nitrogen uptake at maturity, NUE: Nitrogen use efficiency, NUpE: Nitrogen uptake efficiency and NUtE : Nitrogen utilization efficiency.

Table 18. Analysis of covariance for NM, NUE and its components: NUpE and NUtE.

	NM	NUE	NUpE	NUtE
Genotype G	0.8087850	0.030912*	0.33489	0.0032520**
Nitrogen level N	0.0000055427***	3.812e-12***	0.00000040830***	0.0002563***
RVP	2.2e-16***	4.000e-10***	0.00000217732***	0.0003351***
RFFP	0.0009842***	1.790e-08***	0.00000000523***	0.4207195
MT	0.0000004636***	0.240631	0.19834	0.4924055
G*N	0.0001663***	0.001409**	0.00832**	0.9697104
G*RVP	0.0000074631***	1.475e-07***	0.00000125253***	0.0510494.
G*RFFP	0.0212611*	0.050938.	0.03904*	0.7160446
G*MT	0.0028727**	0.001801**	0.00329**	0.4842658
N*RVP	0.1260680	0.357305	0.51538	0.1257300
N*RFFP	0.1717979	0.005410**	0.87259	0.00007245***
N*MT	0.4200217	0.029622*	0.76220	0.0022207**
G*N*RVP	0.0917845	0.242135	0.37923	0.8297873
G*N*RFFP	0.8943161	0.563605	0.90683	0.3829157
G*N*MT	0.9698090	0.725872	0.99107	0.5490996

NM: Nitrogen uptake at maturity, NUE: Nitrogen use efficiency, NUpE: Nitrogen uptake efficiency and NUtE : Nitrogen utilization efficiency, RVP: the total rainfall at vegetative period, RFFP: the total rainfall at flowering and filling period and MT: the mean temperature. **NS=** no significant value, ***=** significant value at $P < 0.05$, ****=** significant value at $P < 0.01$, *****=** significant value at $P < 0.001$, **CV%=** Coefficient of variation.

6.2.1. Total nitrogen uptake at maturity NM

The analysis of covariance indicated a very highly and highly significant effect of all factors, except for genotype effect G (Table 18). The effect of total rainfall at vegetative period (RVP), total rainfall at flowering and filling period (RFFP) and the mean temperature (MT) were very highly and highly significant on total nitrogen uptake at maturity (NM) (Table 18). The mean of NM of all genotypes and all N level combined was different between environments, it was 126 kgN/ha, 115 kgN/ha, 101 kgN/ha and 31,95 kgN/ha respectively in the fourth environment E4, third environment E3, first environment E1, and the second environment E2 (Table 17).

The effect of nitrogen level was highly significant on total nitrogen uptake at maturity (NM) (Table 18, Figure 32). The positive response of NM to nitrogen level increasing was very illustrated in the third and first environments E3 (R2=0,99), E1(R2=0,96) than the two others environments E4(R2=0,79), E2(R2=0,14) (Figure 32).

6.2.2. NUE and its components NUpE and NUtE

The analysis of covariance ANCOVA showed a very highly and highly significant effect of all factors, except for genotype effect on NUpE and the mean temperature (MT) effect, which was not significant on NUE and its components NUpE and NUtE and the RFFP effect on NUtE (Table 18).

The mean value of NUE of all genotypes and all N level combined was different between environments, the lowest value was 8 kg kg-1 in E2 and the higher one was 21 kg kg-1in E4. For the NUpE, the mean value was similar in environments E3 (0,68 kg kg-1) and E4(0,69 kg kg-1) and significantly lower in E2 (0,29 kg kg-1) and very higher in E1 (0,75 kg kg-1).

NUtE was also significantly different between environments: 26.11, 27.34, 24.08 and 30.41 kg kg-1 respectively in E1, E2, E3 and E4.

The response of NUE and its components NUpE and NUtE to N level increasing were negatively significant to N increasing (Table 17 and 18) (Figure 33).

For the genotypes, they showed significant different capacities for the expression of NUE and NUtE (Table 18, Figure 34). The genotype GTAdur gave the best values of NUE and its components NUpE and NUtE with an average of 18.14 kg kg-1, 0.64 kg kg-1, 28.47 kg kg-1 respectively.

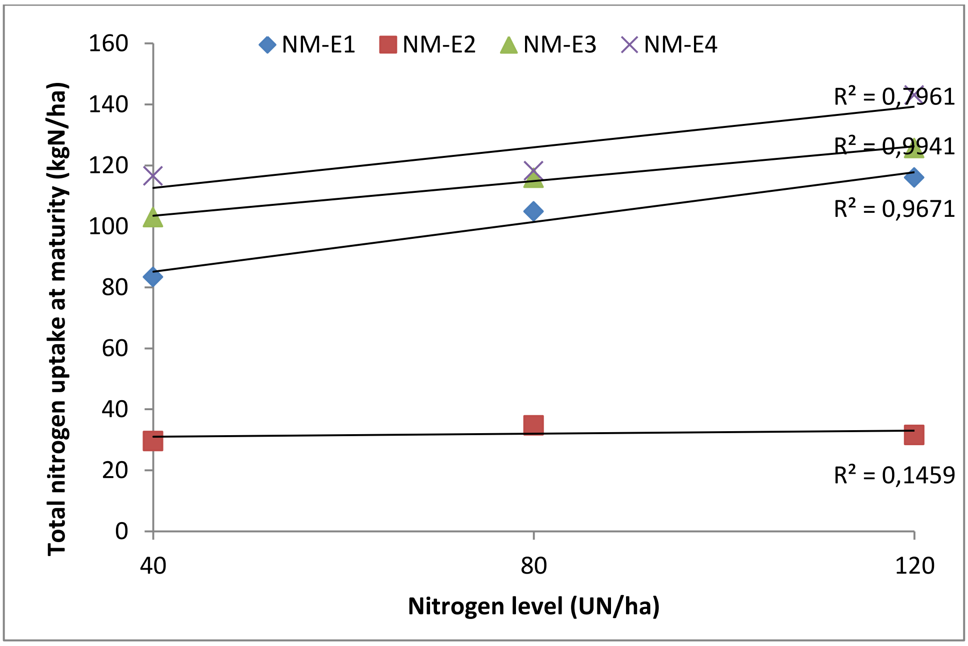


Figure 32. Nitrogen effect on total nitrogen uptake at maturity in the four environments.

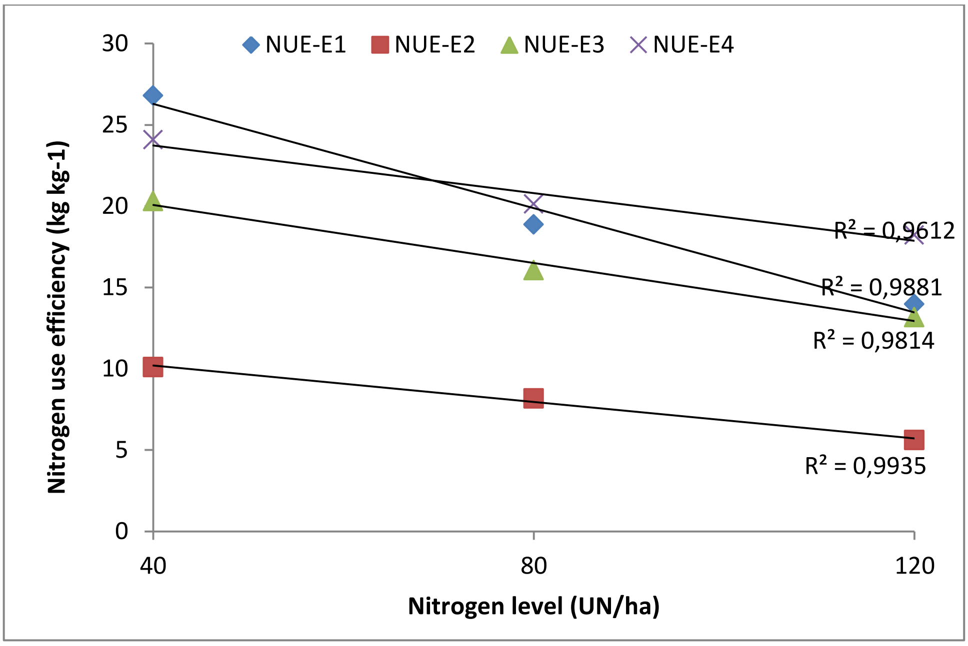


Figure 33. Nitrogen use efficiency in the four environments.

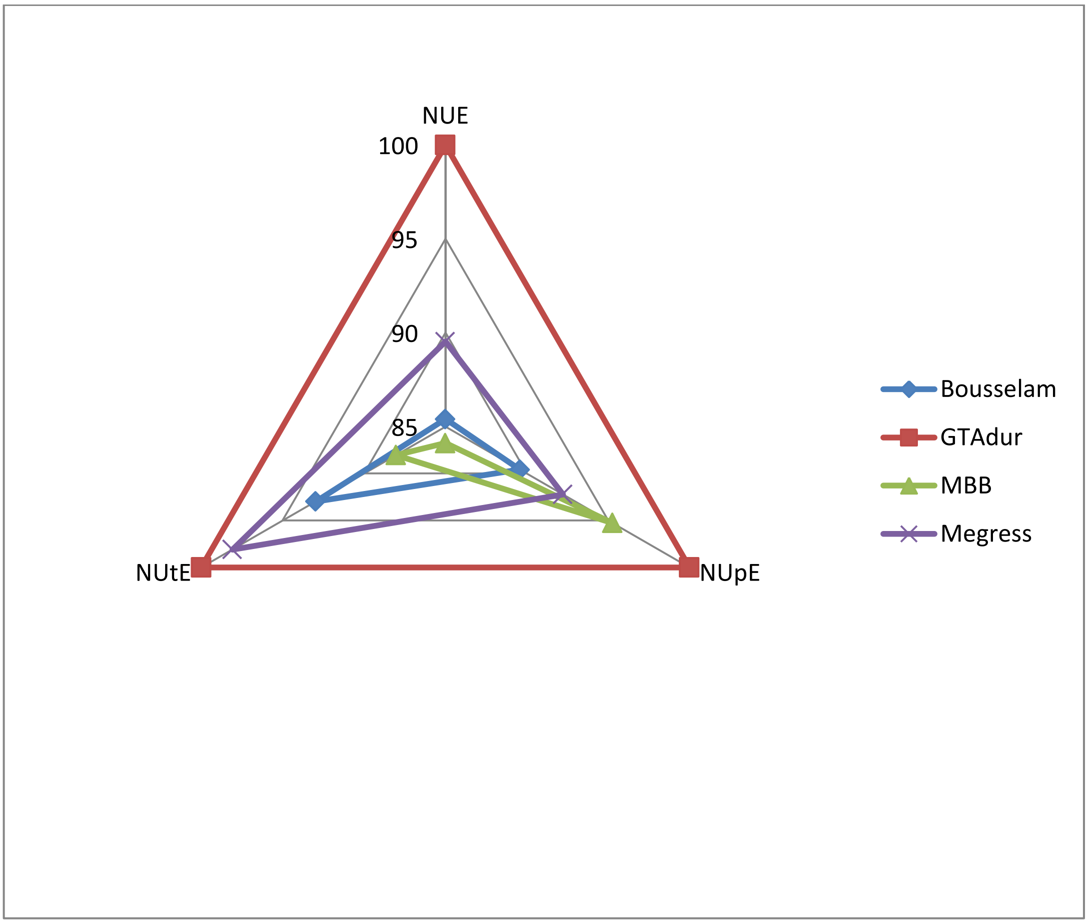


Figure 34. Genotypic performance for NUE and its components.

6.2.3. ANALYSIS OF INTERACTIONS FOR NUE AND ITS COMPONENTS

A. Genotypes x N level interaction (G*N)

Interaction between genotypes and N level was significant for NM, NUE and NUpE (Table 18), Figure 35 showed there was crossover of the regression lines. The nature of the interaction was explained by differences in response of genotypes to N levels.

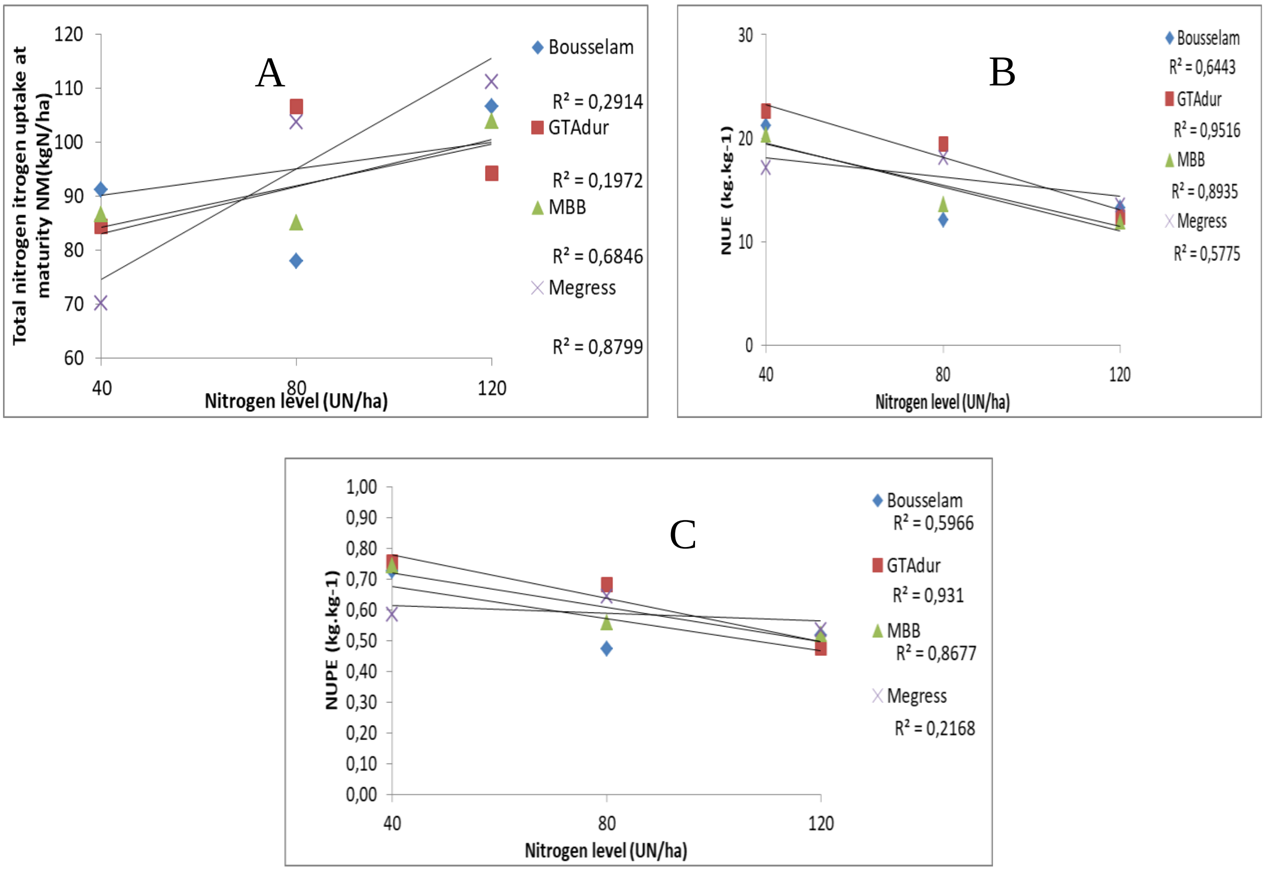


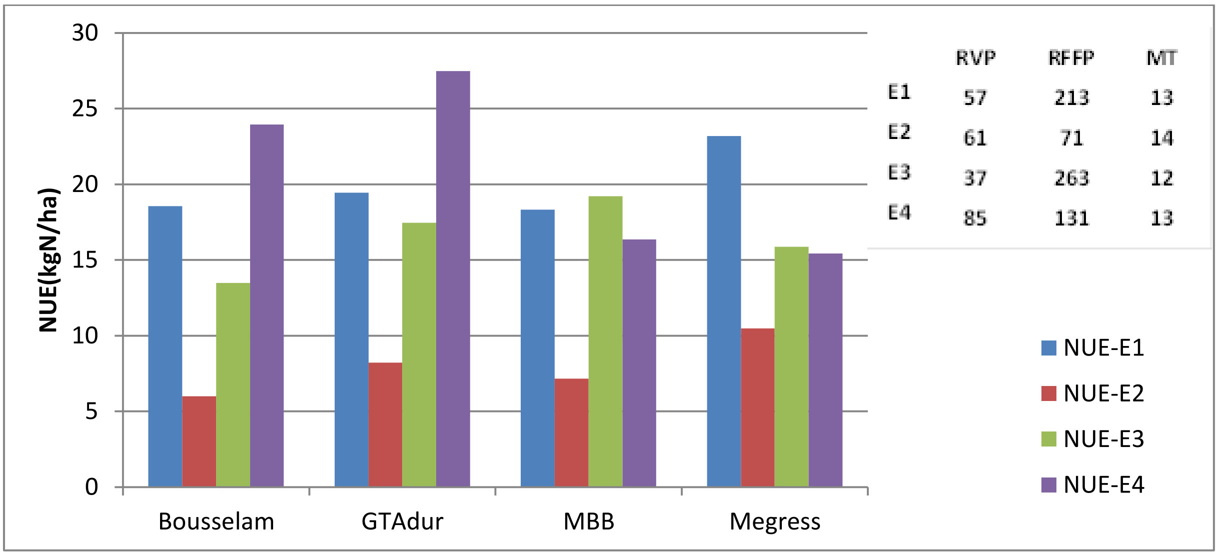
Figure 35. NM (A), NUE(B) and NUpE (C) of 4 genotypes across under the 4 N levels.

B. Genotypes x Environment interaction RVP/RFFP/MT

Interaction between genotypes and the total rainfall at vegetative period (G*RVP), total rainfall at flowering and filling period (G*RFFP) and the mean temperature (G*MT) were significant for all parameters NM, NUE and NUpE except for NUtE (Table 18).

These interactions were explained by differences in response of genotypes in different environments (Figure 36).

The ANCOVA analysis showed that the G*RVP was very highly significant on NUE (Table 18).



	RVP	RFFP	MT
E1	57	213	13
E2	61	71	14
E3	37	263	12
E4	85	131	13

Figure 36. The variation of NUE in the different environments studied (G* Environment interaction)

C. Nitrogen level N x Environment interaction (N*RVP/ N*RFFP/N*MT)

Interaction between nitrogen level and the total rainfall at vegetative period (N*RVP), total rainfall at flowering and filling period (N*RFFP) and the mean temperature (N*MT) were not significant for all parameters except for N*RFFP and N*MT interactions which were significant for NUE and NUtE. The ANCOVA analysis showed that the N*RFFP was very highly significant on NUtE (Table 18).

6.3. DISCUSSION

The objective of this part is to analyze the effect of weather conditions (the total rainfall at vegetative period (RVP), the total rainfall at flowering and filling period (RFFP) and the mean temperature (MT) on grain yield and NUE and their components; which weather conditions highly significantly influences the yield, what genotypes provides stable yields, and what N level represents the optimum under different climatic conditions.

The grain yield was significantly different between environments, it was 2615, 934, 2747 kg ha-1 in the three environments in Algeria respectively (E1, E2, E3) and 3695 kg ha-1 in the fourth environment in Italy (E4). The ANCOVA analysis showed there was no significant effect of N level on grain yield GY. However the effect of genotype and the environmental conditions were very highly significant. From these results, we can say that, the increasing trend in GY is mainly due to the effect of genotypic variation and the weather conditions.

The amount of rainfall during the vegetative period is one of the key environmental factors affecting grain yield in durum wheat. Its effect is critical because it determines the amount of moisture available to the plants and influences their growth and development. In this study, the amount of rainfall during the vegetative period was 57, 61, 37, and 85 mm in the four environments E1, E2, E3, and E4, respectively.

Our results showed that the total rainfall at vegetative period (RVP) was the environmental condition that most affected the grain yield GY (RVP *** GxRVP ***and NxRVP***, P<0, 0001). This result is in agreement with the results obtained by (Garrido and López-Bellido, 2001; Pampana and Mariotti, 2021; Xu et *al.*, 2023), who report that when rainfall over the vegetative period was important, the values of grain yield increased. Moreover (Panayotova et *al.*, 2017), confirm that the nitrogen effect on grain yields of durum wheat was strongly dependent on weather conditions during durum wheat vegetation. However, excessive rainfall during the vegetative period can also have a negative effect on grain yield in durum wheat. As study by Garrido and López-Bellido (2001), found that durum wheat grown under conditions of excessive rainfall during the vegetative period had lower grain.

The total rainfall at vegetative period (RVP) has also a significant effect on NUE and its components. Our results showed that the total rainfall at vegetative period (RVP) was the environmental condition the most affected the NUE (RVP *** NxRVP ***, P<0, 0001).

Several studies have shown that an adequate amount of rainfall during the vegetative period increase NUE by improving NUpE and NUtE. For example, The studies conducted by Mandić et *al*., (2015; Rehim et *al*., (2020) and Lupini et *al*., (2021) showed that, the NUE depends of the water availability and plants that received sufficient rainfall had higher NUE compared to those that received less rainfall.

The amount of rainfall during the flowering and filling period can significantly affect the grain yield in durum wheat. During the flowering stage, adequate moisture is necessary for proper pollination and fertilization of spikes. If there is not enough moisture, the number of viable grains per spike may decrease, resulting lower grain yield. Similarly, during the grain filling period, which usually starts a few weeks after flowering, the plants needs a consistent supply of moisture to support the development of grains. If there is not sufficient moisture, the grain may not fill to their full potential, resulting in smaller and lighter grains a lower yield. In this study, the amount of rainfall during the flowering and filling period was 213, 71, 263 and 131mm in the four environments E1, E2, E3 and E4 respectively.

Our results showed that the total rainfall at flowering and filling period (RFFP) was affected the grain yield GY (RFFP *** P<0, 0001).

The grain yield is the product of a series of components: the number of spike per m2 * grain number per spike* thousand grain weights or grain number per square meter * thousand grain weights(Senapati et *al*., 2019), as it also undergoes to the effects of compensation between components (Bouzerzour et *al*., 2000). In our results, the total rainfall during the flowering and filling period (RFFP) was mainly reduced the grain weight. This result is in agreement with the results obtained by (Chen et *al*., 2019; Xu et *al*., 2023), who reported that under rainfed conditions, the grain weight was a likely potential trait for enhancing grain yield.

CONCLUSION

In the Mediterranean area, several studies have shown that N fertilization is an effective technique for improving bread wheat yield and quality. However, few studies have been carried out in semiarid environments on durum wheat. Hence, the objectives of this study were to fill the knowledge gap on NUE in durum wheat under semiarid conditions and to evaluate the effects of N rates on the agronomic and economic aspects of Algerian durum wheat genotypes, determining the most efficient in terms of N use.

It was shown by the present study how the level of N fertilization improved the nitrogen uptake at maturity by the whole plant (NM) and by the grain (NG); however, no positive effect on grain yield has been observed. Moreover, increasing N application may produce an economic loss of 12%. In other terms in the semi-arid Algerian environment the response to nitrogen is more elucidated on quality than on yield, and it is much dependent on the climatic conditions of each year than the cultivated genotypes. On the other hand, nitrogen supply negatively affected the NUE and its components (NUpE, NUtE).

In semi-arid wheat growing areas (environments with less than 500 mm/year rainfall), to take better advantage of nitrogen and to avoid unjustified contributions, the recommendation that this study generates is to base the management of nitrogen fertilization not only on the levels that avoid economic losses but also on the selection of appropriate genotypes. These, in fact, should be more adapted to tolerate the climatic constraints during flowering and grain filling but also to utilize N more efficiently even in drought conditions.

This study showed that the modern genotypes, Megress, Massinissa, Waha, Sétifis, and GTAdur, expressed better performances in terms of grain yield, and they maintained such performances throughout the years and under different conditions of N availability as well as water shortage. They should give relatively more interesting yields than the other genotypes. Furthermore, the two cultivars Megress and GTAdur above not only have the characteristic of being productive but also of being able to uptake and remobilize the nitrogen in their total aerial part as well as in their grains more than the other genotypes investigated.

The effect of rainfall during the vegetative period, flowering and filling period on grain yield GY and NUE can be both positive and negative, depending on the amount and timing of rainfall. Adequate rainfall can increase GY by improving the number of spikes per m2 and TGW and NUE by improving NUpE and NUtE.

In conclusion, the high variation of climatic conditions between environments and the presence of genetic variation in response to nitrogen fertilization are the results of different behaviors observed.

The yields of durum wheat are significantly affected by weather conditions and climate change. Fluctuating weather patterns, such as irregular rainfall, prolonged droughts, heatwaves, pose significant challenges to durum wheat farmers worldwide, leading to reduced crop yields, lower grain quality, and economic losses, impacting food security and sustainability.

To address these challenges, adapting durum wheat cultivation practices is essential, including developing drought-resistant and heat-tolerant wheat varieties, implementing efficient irrigation systems, and using precision agriculture techniques. Promoting sustainable land management and agroforestry can aid in carbon sequestration and climate change mitigation.

As prospects, collaboration between the scientific community, policymakers, and agricultural stakeholders is crucial to find solutions, invest in research, technological innovations, and climate-smart strategies to safeguard global food production and the livelihoods of farmers. By understanding the interactions between weather conditions, climate change, and durum wheat yields, we can develop adaptive and sustainable solutions to secure the future of durum wheat cultivation amidst a changing climate and contribute to broader global efforts to combat climate change.

PUBLICATION

Nitrogen Use Efficiency in Durum Wheat (Triticum durum Desf.) Grown under Semiarid Conditions in Algeria

Soumia Benchelali [1,2],Nadjat Benkherbache [1],Mohamed Mefti [1],Domenico Ronga [3],Nasreddine Louahdi [4],Mario Russo [5] and Nicola Pecchioni [5]

https://doi.org/10.3390/agronomy12061284

PRESENTATIONS

- The effect of climate change on the durum wheat production in Algeria
  Soumia Benchelali[1,2], Zahira Bouziane[2], Nadjet Benkherbache[1], Mohamed Mefti[1]
  Le premier Séminaire International sur la Biotechnologie Verte et Sécurité Alimentaire (Webinaire) 16-17 Novembre 2022-Université Abbès Laghrour –Khenchela-
- L'évaluation de l'activité d'assimilation de l'azote chez quelques variétés de blé dur au stade germination-levée.
  Bouaroui Yassine[1], Ramdani Marouane[1] Et Benchelali Soumia[1]

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ANNEXES

Annex 1. Results ANOVA of morphological, physiological and qualitative traits

The GLM Procedure
Class Level Information

```
Class        Levels    Values
Varieties         7    Bousselam Gtadur MBB Massinissa Megress Sètifis Waha

Doses             4    0 40 80 120

Number of Observations Read        84
Number of Observations Used        84
1                                            01:41 Friday, June 9, 2022   2

The GLM Procedure
Dependent Variable: Heigh_cm_   Heigh(cm)

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   27     4907.211640      181.748579       6.56    <.0001

Error                 56     1551.629630       27.707672

Corrected Total           83     6458.841270

R-Square     Coeff Var      Root MSE    Heigh_cm_ Mean

0.759767      6.340118      5.263808         83.02381

Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Doses                    3       46.608466       15.536155       0.56    0.6432
Varieties                6     4438.526455      739.754409      26.70    <.0001
Varieties*Doses           18      422.076720       23.448707       0.85    0.6406
1                                            01:41 Friday, June 9, 2022   3

The GLM Procedure
Dependent Variable: Neck_lenght_cm_   Neck lenght(cm)

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   27     370.1706217      13.7100230       2.08    0.0103

Error                 56     368.3444444       6.5775794

Corrected Total           83     738.5150661


R-Square     Coeff Var      Root MSE    Neck_lenght_cm_ Mean

0.501236      8.819705      2.564679              29.07897


Source                  DF     Type III SS     Mean Square    F Value    Pr > F
```

```
Doses                    3      14.8595106       4.9531702       0.75    0.5252
Varieties                6     216.5544180      36.0924030       5.49    0.0002
Varieties*Doses         18     138.7566931       7.7087052       1.17    0.3148
1                                          01:41 Friday, June 9, 2022   4

The GLM Procedure

Dependent Variable: Spike_lenght__cm_   Spike lenght (cm)

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   27     13.57603423      0.50281608       2.95    0.0003

Error                   56      9.54208333      0.17039435

Corrected Total         83     23.11811756


R-Square     Coeff Var      Root MSE    Spike_lenght__cm_ Mean

0.587247      5.996668      0.412788                6.883631


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Doses                    3      0.19656994      0.06552331       0.38    0.7645
Varieties                6     11.81629464      1.96938244      11.56    <.0001
Varieties*Doses         18      1.56316964      0.08684276       0.51    0.9424
1                                          01:41 Friday, June 9, 2022   5

The GLM Procedure

Dependent Variable: Awns_lenght_cm_   Awns lenght(cm)

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   27     41.75234375      1.54638310       4.75    <.0001

Error                   56     18.21875000      0.32533482

Corrected Total         83     59.97109375


R-Square     Coeff Var      Root MSE    Awns_lenght_cm_ Mean

0.696208      5.241873      0.570381              10.88125


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Doses                    3      1.74740327      0.58246776       1.79    0.1595
Varieties                6     33.73552083      5.62258681      17.28    <.0001
Varieties*Doses         18      6.26941964      0.34830109       1.07    0.4038
1                                          01:41 Friday, June 9, 2022   6

The GLM Procedure
```

```
Dependent Variable: Humidity   Humidity

Sum of
Source                  DF         Squares     Mean Square    F Value    Pr > F

Model                   27      0.68904762      0.02552028       2.49    0.0020

Error                 56      0.57333333      0.01023810

Corrected Total           83      1.26238095


R-Square     Coeff Var      Root MSE    Humidity Mean

0.545832      0.978519      0.101183        10.34048


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Doses                    3      0.05952381      0.01984127       1.94    0.1339
Varieties                6      0.39738095      0.06623016       6.47    <.0001
Varieties*Doses           18      0.23214286      0.01289683       1.26    0.2498
1                                           01:41 Friday, June 9, 2022   7

The GLM Procedure

Dependent Variable: Proteine__TP__   Proteine (TP%)

Sum of
Source                  DF         Squares     Mean Square    F Value    Pr > F

Model                   27     23.97285714      0.88788360       1.50    0.1009

Error                 56     33.18666667      0.59261905

Corrected Total           83     57.15952381


R-Square     Coeff Var      Root MSE    Proteine__TP__ Mean

0.419403      4.956667      0.769818            15.53095


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Doses                    3     10.16142857      3.38714286       5.72    0.0017
Varieties                6      9.30452381      1.55075397       2.62    0.0263
Varieties*Doses           18      4.50690476      0.25038360       0.42    0.9769
1                                           01:41 Friday, June 9, 2022   8

The GLM Procedure

Dependent Variable: Dry_gluten_DG_   Dry gluten(DG)

Sum of
Source                  DF         Squares     Mean Square    F Value    Pr > F

Model                   27      61.7667369       2.2876569       1.30    0.1999

Error                 56      98.3734667       1.7566690
```

```
Corrected Total            83     160.1402036


R-Square     Coeff Var      Root MSE    Dry_gluten_DG_ Mean

0.385704      9.936285      1.325394              13.33893


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Doses                      3     11.95589881      3.98529960       2.27    0.0905
Varieties                  6     37.00159524      6.16693254       3.51    0.0051
Varieties*Doses           18     12.80924286      0.71162460       0.41    0.9815
1                                              01:41 Friday, June 9, 2022   9

The GLM Procedure

Dependent Variable: _Specific_Weight_SpW_    Specific Weight(SpW)

Sum of
Source                    DF         Squares     Mean Square    F Value    Pr > F

Model                     27     265.7547476       9.8427684       3.78    <.0001

Error                     56     145.9536667       2.6063155

Corrected Total           83     411.7084143


R-Square     Coeff Var      Root MSE    _Specific_Weight_SpW_ Mean

0.645493      2.055992      1.614409                    78.52214


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Doses                      3       8.1396238       2.7132079       1.04    0.3816
Varieties                  6     240.3828476      40.0638079      15.37    <.0001
Varieties*Doses           18      17.2322762       0.9573487       0.37    0.9892
1                                              01:41 Friday, June 9, 2022  10

The GLM Procedure
Least Squares Means

Spike_
Heigh_cm_   Neck_lenght_    lenght__cm_   Awns_lenght_      Humidity     Proteine__
Doses        LSMEAN      cm_ LSMEAN        LSMEAN      cm_ LSMEAN         LSMEAN    TP__ LSMEAN

0        84.0317460     29.4761905     6.96190476     10.6476190     10.3619048     15.3333333
40        81.9365079     28.8015873     6.84404762     10.8964286     10.3714286     15.3333333
80        83.1587302     29.5015873     6.88571429     11.0380952     10.3190476     15.3238095
120       82.9682540     28.5365079     6.84285714     10.9428571     10.3095238     16.1333333

_Specific_
Dry_gluten_     Weight_SpW_
Doses     DG_ LSMEAN          LSMEAN

0        12.9333333     78.6385714
40        13.1528571     78.9590476
```

```
80       13.3223810      78.1228571
120       13.9471429      78.3680952
1                                         01:41 Friday, June 9, 2022  11

The GLM Procedure
Least Squares Means

Spike_
Heigh_cm_  Neck_lenght_   lenght__cm_  Awns_lenght_     Humidity    Proteine__
Varieties        LSMEAN    cm_ LSMEAN       LSMEAN    cm_ LSMEAN       LSMEAN   TP__ LSMEAN

Bousselam     77.9166667    29.7777778    6.80000000    11.3000000    10.2666667    15.8250000
Gtadur       76.5277778    27.2722222    7.41666667    10.0916667    10.2916667    15.1583333
MBB          99.5277778    31.9722222    6.14375000     9.9354167    10.3916667    15.0750000
Massinissa    82.0833333    27.8333333    6.85833333    11.7833333    10.4833333    15.3250000
Megress      85.5277778    28.4027778    6.72500000    10.7250000    10.3166667    15.5000000
Sètifis      80.5555556    30.5444444    7.05833333    11.4083333    10.3333333    15.8916667
Waha         79.0277778    27.7500000    7.18333333    10.9250000    10.3000000    15.9416667

_Specific_
Dry_gluten_     Weight_SpW_
Varieties     DG_ LSMEAN         LSMEAN

Bousselam     13.8275000      77.5950000
Gtadur        12.7000000      80.3075000
MBB           13.2758333      81.6816667
Massinissa    12.1758333      76.3858333
Megress       13.8033333      78.3100000
Sètifis       13.3216667      77.6791667
Waha          14.2683333      77.6958333
```

Annex 2. Results ANOVA of dry matter accumulation.

The GLM Procedure
Class Level Information

```
Class        Levels    Values
Ann_e           3    2016 2017 2018
Vari_t_s        7    V1 V2 V3 V4 V5 V6 V7

Doses          4    N0 N1 N2 N3

Bloc_          3    1 2 3


Number of Observations Read        252
Number of Observations Used        252
1                                       13:07 Thursday, June 10, 2022   2

The GLM Procedure

Dependent Variable: DMST_F_kg_ha_   DMST-F(kg/ha)

Sum of
Source                   DF        Squares     Mean Square    F Value    Pr > F

Model                    83     771697754.6       9297563.3       12.98    <.0001

Error                   168     120338703.7        716301.8
```

```
Corrected Total          251     892036458.3


R-Square     Coeff Var      Root MSE    DMST_F_kg_ha_ Mean

0.865097      25.02543      846.3462             3381.944


Source                   DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                     2     696866673.3     348433336.6     486.43    <.0001
Doses                     3       3617992.7       1205997.6       1.68    0.1724
Vari_t_s                  6      15559660.5       2593276.7       3.62    0.0021
Ann_e*Doses               6       2125522.5        354253.7       0.49    0.8118
Ann_e*Vari_t_s           12      19938712.5       1661559.4       2.32    0.0091
Vari_t_s*Doses           18      13901953.3        772330.7       1.08    0.3781
Ann_e*Vari_t_s*Doses     36      19687239.9        546867.8       0.76    0.8288
1                                             13:07 Thursday, June 10, 2022   3

The GLM Procedure

Dependent Variable: DMS_F_kg_ha_   DMS-F(kg/ha)

Sum of
Source                   DF         Squares     Mean Square    F Value    Pr > F

Model                    83     51843408.29       624619.38      11.92    <.0001

Error                   168      8800370.37        52383.16

Corrected Total         251     60643778.66


R-Square     Coeff Var      Root MSE    DMS_F_kg_ha_ Mean

0.854884      22.44500      228.8737             1019.709


Source                   DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                     2     37277416.23     18638708.11     355.81    <.0001
Doses                     3      1354828.04       451609.35       8.62    <.0001
Vari_t_s                  6      6859303.35      1143217.23      21.82    <.0001
Ann_e*Doses               6      1403148.15       233858.02       4.46    0.0003
Ann_e*Vari_t_s           12      1926688.71       160557.39       3.07    0.0006
Vari_t_s*Doses           18      1320758.38        73375.47       1.40    0.1367
Ann_e*Vari_t_s*Doses     36      1701265.43        47257.37       0.90    0.6311
1                                             13:07 Thursday, June 10, 2022   4

The GLM Procedure

Dependent Variable: DM_F_kg_ha_   DM-F(kg/ha)

Sum of
Source                   DF         Squares     Mean Square    F Value    Pr > F

Model                    83      1160549959        13982530      13.78    <.0001

Error                   168       170417963         1014393
```

```
Corrected Total          251     1330967922


R-Square     Coeff Var      Root MSE    DM_F_kg_ha_ Mean

0.871959      22.88164      1007.171            4401.653


Source                     DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                       2      1051387608       525693804     518.24    <.0001
Doses                       3         9375012         3125004       3.08    0.0290
Vari_t_s                    6        12154350         2025725       2.00    0.0688
Ann_e*Doses                 6         6803688         1133948       1.12    0.3540
Ann_e*Vari_t_s             12        29372377         2447698       2.41    0.0066
Vari_t_s*Doses             18        21858067         1214337       1.20    0.2684
Ann_e*Vari_t_s*Doses       36        29598858          822191       0.81    0.7679
1                                              13:07 Thursday, June 10, 2022   5

The GLM Procedure

Dependent Variable: DMST_M_kg_ha_   DMST-M(kg/ha)

Sum of
Source                     DF         Squares     Mean Square    F Value    Pr > F

Model                      83     548832985.0       6612445.6      21.63    <.0001

Error                     168      51366296.3        305751.8

Corrected Total           251     600199281.3


R-Square     Coeff Var      Root MSE    DMST_M_kg_ha_ Mean

0.914418      18.69957      552.9482              2957.011


Source                     DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                       2     477152707.2     238576353.6     780.29    <.0001
Doses                       3       3017050.3       1005683.4       3.29    0.0221
Vari_t_s                    6      23965762.8       3994293.8      13.06    <.0001
Ann_e*Doses                 6       3975476.2        662579.4       2.17    0.0486
Ann_e*Vari_t_s             12      22873496.5       1906124.7       6.23    <.0001
Vari_t_s*Doses             18       9083505.3        504639.2       1.65    0.0531
Ann_e*Vari_t_s*Doses       36       8764986.8        243471.9       0.80    0.7871
1                                              13:07 Thursday, June 10, 2022   6

The GLM Procedure

Dependent Variable: DMS_M_kg_ha_   DMS-M(kg/ha)

Sum of
Source                     DF         Squares     Mean Square    F Value    Pr > F

Model                      83     515219694.7       6207466.2      16.97    <.0001

Error                     168      61462777.8        365849.9
```

```
Corrected Total           251     576682472.4


R-Square     Coeff Var      Root MSE    DMS_M_kg_ha_ Mean

0.893420      18.14746      604.8552            3333.003


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                      2     459085068.3     229542534.2     627.42    <.0001
Doses                      3       641220.2        213740.1       0.58    0.6261
Vari_t_s                   6      13558560.4      2259760.1       6.18    <.0001
Ann_e*Doses                6       2142242.1        357040.3       0.98    0.4432
Ann_e*Vari_t_s            12      13218033.5       1101502.8       3.01    0.0008
Vari_t_s*Doses            18      13956642.4        775369.0       2.12    0.0071
Ann_e*Vari_t_s*Doses      36      12617927.7        350498.0       0.96    0.5429
1                                               13:07 Thursday, June 10, 2022   7

The GLM Procedure

Dependent Variable: DM_M_kg_ha_   DM-M(kg/ha)

Sum of
Source                    DF         Squares     Mean Square    F Value    Pr > F

Model                     83      1981535700        23873924      21.18    <.0001

Error                    168       189392778         1127338

Corrected Total           251      2170928478


R-Square     Coeff Var      Root MSE    DM_M_kg_ha_ Mean

0.912760      16.88012      1061.762           6290.013


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                      2      1829471933       914735967     811.41    <.0001
Doses                      3         4742384         1580795       1.40    0.2440
Vari_t_s                   6        17232158         2872026       2.55    0.0219
Ann_e*Doses                6         7847546         1307924       1.16    0.3301
Ann_e*Vari_t_s            12        45837557         3819796       3.39    0.0002
Vari_t_s*Doses            18        40268009         2237112       1.98    0.0130
Ann_e*Vari_t_s*Doses      36        36136111         1003781       0.89    0.6494
1                                               13:07 Thursday, June 10, 2022   8

The GLM Procedure

Dependent Variable: GY_kg_ha_   GY(kg/ha)

Sum of
Source                    DF         Squares     Mean Square    F Value    Pr > F

Model                     83     243281255.5       2931099.5      13.63    <.0001

Error                    168      36140185.2        215120.1
```

```
Corrected Total           251     279421440.7


R-Square     Coeff Var      Root MSE    GY_kg_ha_ Mean

0.870661      21.30454      463.8105         2177.050


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                      2     205660425.5     102830212.7     478.01    <.0001
Doses                      3        650188.5        216729.5       1.01    0.3909
Vari_t_s                   6       8260321.9       1376720.3       6.40    <.0001
Ann_e*Doses                6        871461.6        145243.6       0.68    0.6699
Ann_e*Vari_t_s            12      10495948.0        874662.3       4.07    <.0001
Vari_t_s*Doses            18       7518461.2        417692.3       1.94    0.0157
Ann_e*Vari_t_s*Doses      36       9824448.9        272901.4       1.27    0.1605
1                                          13:07 Thursday, June 10, 2022   9

The GLM Procedure

Dependent Variable: NbrS_m2   NbrS/m2

Sum of
Source                    DF         Squares     Mean Square    F Value    Pr > F

Model                     83     1203135.571       14495.609       7.19    <.0001

Error                    168      338742.593        2016.325

Corrected Total           251     1541878.164


R-Square     Coeff Var      Root MSE    NbrS_m2 Mean

0.780305      17.59325      44.90351        255.2315


Source                    DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                      2     736646.9797     368323.4899     182.67    <.0001
Doses                      3      46696.3294      15565.4431       7.72    <.0001
Vari_t_s                   6     108609.1049      18101.5175       8.98    <.0001
Ann_e*Doses                6      16920.5688       2820.0948       1.40    0.2179
Ann_e*Vari_t_s            12     149456.1067      12454.6756       6.18    <.0001
Vari_t_s*Doses            18      44022.1120       2445.6729       1.21    0.2557
Ann_e*Vari_t_s*Doses      36     100784.3695       2799.5658       1.39    0.0869
1                                          13:07 Thursday, June 10, 2022  10

The GLM Procedure

Dependent Variable: Nbr_G_m2   Nbr G/m2

Sum of
Source                    DF         Squares     Mean Square    F Value    Pr > F

Model                     83      1386382295        16703401      11.44    <.0001

Error                    168       245282979         1460018
```

```
Corrected Total          251      1631665274


R-Square     Coeff Var      Root MSE    Nbr_G_m2 Mean

0.849673      21.02867      1208.312         5746.022


Source                      DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                        2      1095397619       547698810     375.13    <.0001
Doses                        3        12943331         4314444       2.96    0.0341
Vari_t_s                     6        81479101        13579850       9.30    <.0001
Ann_e*Doses                  6        16491828         2748638       1.88    0.0865
Ann_e*Vari_t_s              12        63878472         5323206       3.65    <.0001
Vari_t_s*Doses              18        48899928         2716663       1.86    0.0222
Ann_e*Vari_t_s*Doses        36        67292015         1869223       1.28    0.1516
1                                                13:07 Thursday, June 10, 2022  11

The GLM Procedure

Dependent Variable: TGW__g_   TGW (g)

Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Model                       83     6888.241071       82.990856       7.54    <.0001

Error                      168     1850.000000       11.011905

Corrected Total            251     8738.241071


R-Square     Coeff Var      Root MSE    TGW__g_ Mean

0.788287      8.987496      3.318419        36.92262


Source                      DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                        2     2999.541667     1499.770833     136.20    <.0001
Doses                        3      585.058532      195.019511      17.71    <.0001
Vari_t_s                     6     1675.345238      279.224206      25.36    <.0001
Ann_e*Doses                  6      519.021825       86.503638       7.86    <.0001
Ann_e*Vari_t_s              12      407.666667       33.972222       3.09    0.0006
Vari_t_s*Doses              18      214.448413       11.913801       1.08    0.3744
Ann_e*Vari_t_s*Doses        36      487.158730       13.532187       1.23    0.1936
1                                                13:07 Thursday, June 10, 2022  12

The GLM Procedure

Dependent Variable: Nbr_G_S   Nbr G/S

Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F

Model                       83     12010.20258       144.70124       3.92    <.0001

Error                      168      6208.69533        36.95652
```

```
Corrected Total          251     18218.89790


R-Square     Coeff Var      Root MSE    Nbr_G_S Mean

0.659217      26.98971      6.079187        22.52409


Source                   DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                     2     7702.519994     3851.259997     104.21    <.0001
Doses                     3      183.537826       61.179275       1.66    0.1786
Vari_t_s                  6     1258.459469      209.743245       5.68    <.0001
Ann_e*Doses               6       38.540633        6.423439       0.17    0.9836
Ann_e*Vari_t_s           12     1080.590262       90.049189       2.44    0.0060
Vari_t_s*Doses           18      563.907016       31.328168       0.85    0.6420
Ann_e*Vari_t_s*Doses     36     1182.647378       32.851316       0.89    0.6517
1                                            13:07 Thursday, June 10, 2022  13

The GLM Procedure

Dependent Variable: HI___   HI(%)

Sum of
Source                   DF         Squares     Mean Square    F Value    Pr > F

Model                    83      5866.10368        70.67595       2.68    <.0001

Error                   168      4430.33314        26.37103

Corrected Total         251     10296.43682


R-Square     Coeff Var      Root MSE    HI___ Mean

0.569722      14.68219      5.135273      34.97622


Source                   DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                     2     1452.709406      726.354703      27.54    <.0001
Doses                     3      105.504919       35.168306       1.33    0.2652
Vari_t_s                  6     1686.368132      281.061355      10.66    <.0001
Ann_e*Doses               6      299.635745       49.939291       1.89    0.0846
Ann_e*Vari_t_s           12      905.224893       75.435408       2.86    0.0013
Vari_t_s*Doses           18      574.723702       31.929095       1.21    0.2574
Ann_e*Vari_t_s*Doses     36      841.936879       23.387136       0.89    0.6550
1                                            13:07 Thursday, June 10, 2022  14

The GLM Procedure
Least Squares Means

        DMST_F_kg_  DMS_F_kg_ha_   DM_F_kg_ha_   DMST_M_kg_  DMS_M_kg_ha_   DM_M_kg_ha_
Ann_e   ha_ LSMEAN        LSMEAN        LSMEAN   ha_ LSMEAN        LSMEAN        LSMEAN

2016    5469.24603    1450.39683    6919.64286   4385.71429    4282.73810    8668.45238
2017    1400.00000     516.66667    1916.66667   1098.41270    1424.20635    2522.61905
2018    3276.58730    1092.06349    4368.65079   3386.90476    4292.06349    7678.96825
```

```
GY_kg_ha_       NbrS_m2      Nbr_G_m2       TGW__g_       Nbr_G_S
Ann_e        LSMEAN        LSMEAN        LSMEAN        LSMEAN        LSMEAN   HI___ LSMEAN

2016      2748.01587     262.797619     7219.83690     38.3571429     28.7024928     31.7811786
2017       901.78571     185.555556     2797.52542     32.1666667     15.2853313     35.5783053
2018      2881.34921     317.341270     7220.70346     40.2440476     23.5844569     37.5691649
1                                              13:07 Thursday, June 10, 2022  15

The GLM Procedure
Least Squares Means

DMST_F_kg_   DMS_F_kg_ha_    DM_F_kg_ha_     DMST_M_kg_   DMS_M_kg_ha_    DM_M_kg_ha_
Doses     ha_ LSMEAN        LSMEAN        LSMEAN     ha_ LSMEAN        LSMEAN        LSMEAN

N0       3210.58201      908.99471     4119.57672     2842.59259     3366.93122     6209.52381
N1       3332.01058      998.41270     4330.42328     2856.87831     3249.47090     6106.34921
N2       3469.31217     1079.36508      4548.67725     3034.65608     3378.04233     6412.69841
N3       3515.87302     1092.06349     4607.93651     3093.91534     3337.56614     6431.48148

GY_kg_ha_       NbrS_m2      Nbr_G_m2       TGW__g_       Nbr_G_S
Doses        LSMEAN        LSMEAN        LSMEAN        LSMEAN        LSMEAN   HI___ LSMEAN

N0       2243.91534     240.158730     5548.48770     39.2380952     23.2649256     35.9764251
N1       2114.81481     246.428571     5504.61344     37.2777778     22.3021368     34.8110007
N2       2206.08466     258.465608     6042.35846     35.9285714     23.3088272     34.9449581
N3       2143.38624     275.873016     5888.62810     35.2460317     21.2204851     34.1724811
1                                              13:07 Thursday, June 10, 2022  16

The GLM Procedure
Least Squares Means

DMST_F_kg_   DMS_F_kg_ha_    DM_F_kg_ha_     DMST_M_kg_   DMS_M_kg_ha_    DM_M_kg_ha_
Vari_t_s     ha_ LSMEAN        LSMEAN        LSMEAN     ha_ LSMEAN        LSMEAN        LSMEAN

V1         3264.35185      941.20370     4205.55556     2938.88889     3012.50000     5951.38889
V2         3517.59259     1266.20370      4783.79630     2797.68519     3490.27778     6287.96296
V3         3887.50000      685.18519     4572.68519     3688.42593     3006.48148     6694.90741
V4         3161.11111     1012.50000      4173.61111     2787.96296     3340.27778     6128.24074
V5         3458.79630     1060.18519      4518.98148     2868.51852     3619.90741     6488.42593
V6         3286.11111     1110.18519      4396.29630     2919.90741     3574.07407     6493.98148
V7         3098.14815     1062.50000      4160.64815     2697.68519     3287.50000     5985.18519

GY_kg_ha_       NbrS_m2      Nbr_G_m2       TGW__g_       Nbr_G_S
Vari_t_s        LSMEAN        LSMEAN        LSMEAN        LSMEAN        LSMEAN   HI___ LSMEAN

V1         1893.51852     290.740741     4998.82092     36.6250000     18.2850201     33.1250042
V2         2312.50000     276.203704     6646.20663     34.1527778     23.2840504     37.2271107
V3         1931.01852     235.833333     4951.85152     37.1944444     20.6269166     29.6602165
V4         2211.11111     257.962963     6161.81214     34.7500000     23.5038371     35.3113535
V5         2396.29630     256.203704     5612.11808     42.5000000     22.1800277     37.7630705
V6         2321.75926     227.777778     5991.24564     37.7777778     25.3922207     35.3249647
V7         2173.14815     241.898148     5860.09855     35.4583333     24.3965830     36.4217938
1
```

Annex 3. Results ANOVA of NUE and its components

```
The GLM Procedure
Class Level Information

Class        Levels    Values

Ann_e            3    2016 2017 2018

Vari_t_s         4    Bousselam GTAdur MBB Megress

Doses            3    40 80 120

Bloc_            3    1 2 3


Number of Observations Read        108
Number of Observations Used        108
1                                          21:43 Thursday, July 29, 2019   2

The GLM Procedure

Dependent Variable: NM_kgN_ha_   NM(kgN/ha)

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                    37     167530.9450       4527.8634      15.52    <.0001

Error                   70      20417.8848        291.6841

Corrected Total           107     187948.8299


R-Square     Coeff Var      Root MSE    NM_kgN_ha_ Mean

0.891365      20.63674      17.07876          82.75902


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                    2     142625.3661      71312.6830     244.49    <.0001
Bloc_                   2        880.7216       440.3608       1.51    0.2281
Doses                   2       6858.4988       3429.2494      11.76    <.0001
Vari_t_s                 3       3851.3038       1283.7679       4.40    0.0068
Ann_e*Doses              4       2975.0687        743.7672       2.55    0.0467
Ann_e*Vari_t_s            6       3831.5958        638.5993       2.19    0.0541
Vari_t_s*Doses           6       3539.4970        589.9162       2.02    0.0740
Ann_e*Vari_t_s*Doses       12       2968.8932        247.4078       0.85    0.6016
1                                          21:43 Thursday, July 29, 2019   3

The GLM Procedure

Dependent Variable: GY_kg_ha_   GY(kg/ha)
```

```
Sum of
Source                  DF         Squares     Mean Square    F Value    Pr > F

Model                    37      94584601.3       2556340.6      10.17    <.0001

Error                   70      17597587.4        251394.1

Corrected Total           107     112182188.8


R-Square     Coeff Var      Root MSE    GY_kg_ha_ Mean

0.843134      24.14373      501.3922          2076.698


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                    2     77684480.45     38842240.23     154.51    <.0001
Bloc_                   2      1650005.14       825002.57       3.28    0.0434
Doses                   2       133677.98        66838.99       0.27    0.7673
Vari_t_s                 3      4656057.10      1552019.03       6.17    0.0009
Ann_e*Doses              4       275025.72        68756.43       0.27    0.8941
Ann_e*Vari_t_s            6      3138873.46       523145.58       2.08    0.0663
Vari_t_s*Doses           6      4074058.64       679009.77       2.70    0.0204
Ann_e*Vari_t_s*Doses       12      2972422.84       247701.90       0.99    0.4715
1                                              21:43 Thursday, July 29, 2019   4

The GLM Procedure

Dependent Variable: NUE   NUE

Sum of
Source                  DF         Squares     Mean Square    F Value    Pr > F

Model                    37     5014.789168      135.534842       7.75    <.0001

Error                   70     1224.513009       17.493043

Corrected Total           107     6239.302178


R-Square     Coeff Var      Root MSE      NUE Mean

0.803742      28.30233      4.182469      14.77783


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                    2     2715.824336     1357.912168      77.63    <.0001
Bloc_                   2       77.476578       38.738289       2.21    0.1168
Doses                   2     1205.783929      602.891964      34.46    <.0001
Vari_t_s                 3      202.582878       67.527626       3.86    0.0129
Ann_e*Doses              4      230.293019       57.573255       3.29    0.0157
Ann_e*Vari_t_s            6      192.432802       32.072134       1.83    0.1050
Vari_t_s*Doses           6      199.711452       33.285242       1.90    0.0924
Ann_e*Vari_t_s*Doses       12      190.684174       15.890348       0.91    0.5432
1                                              21:43 Thursday, July 29, 2019   6

The GLM Procedure
```

```
Dependent Variable: NUpE   NUpE

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   37      6.00177548      0.16221015      10.16    <.0001

Error                   70      1.11783949      0.01596914

Corrected Total        107      7.11961497


R-Square     Coeff Var      Root MSE     NUpE Mean

0.842992      22.05005      0.126369      0.573101


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                    2      4.35935045      2.17967523     136.49    <.0001
Bloc_                    2      0.06883149      0.03441574       2.16    0.1235
Doses                    2      0.66491138      0.33245569      20.82    <.0001
Vari_t_s                 3      0.25358357      0.08452786       5.29    0.0024
Ann_e*Doses              4      0.00394891      0.00098723       0.06    0.9928
Ann_e*Vari_t_s           6      0.29271491      0.04878582       3.06    0.0103
Vari_t_s*Doses           6      0.17257044      0.02876174       1.80    0.1114
Ann_e*Vari_t_s*Doses    12      0.18586433      0.01548869       0.97    0.4855
1                                          21:43 Thursday, July 29, 2019   7

The GLM Procedure

Dependent Variable: NUtE   NUtE

Sum of
Source                  DF        Squares     Mean Square    F Value    Pr > F

Model                   37     1633.750801       44.155427       2.67    0.0002

Error                   70     1156.182809       16.516897

Corrected Total        107     2789.933610


R-Square     Coeff Var      Root MSE     NUtE Mean

0.585588      15.72579      4.064099      25.84353


Source                  DF     Type III SS     Mean Square    F Value    Pr > F

Ann_e                    2     195.4686573      97.7343287       5.92    0.0042
Bloc_                    2      75.0626750      37.5313375       2.27    0.1106
Doses                    2     336.3882198     168.1941099      10.18    0.0001
Vari_t_s                 3     361.9290140     120.6430047       7.30    0.0002
Ann_e*Doses              4     408.0304363     102.0076091       6.18    0.0003
Ann_e*Vari_t_s           6      69.7893532      11.6315589       0.70    0.6472
Vari_t_s*Doses           6      42.8008468       7.1334745       0.43    0.8552
Ann_e*Vari_t_s*Doses    12     144.2815982      12.0234665       0.73    0.7195
1                                          21:43 Thursday, July 29, 2019   8
```

```
The GLM Procedure
Least Squares Means

NM_kgN_ha_      GY_kg_ha_      N_supply_
Ann_e        LSMEAN        LSMEAN        LSMEAN     NUE LSMEAN    NUpE LSMEAN    NUtE LSMEAN

2016     101.449556     2592.59259     139.613889     19.8729870     0.74616233     26.1109409
2017      31.954060     881.01852     118.644556      7.9583273     0.29141948     27.3411526
2018     114.873435     2756.48148     175.790417     16.5021625     0.68172127     24.0785079
1                                             21:43 Thursday, July 29, 2019   9

The GLM Procedure
Least Squares Means

NM_kgN_ha_      GY_kg_ha_      N_supply_
Doses        LSMEAN        LSMEAN        LSMEAN     NUE LSMEAN    NUpE LSMEAN    NUtE LSMEAN

40       72.0180046     2038.88889     104.682954     19.0639831     0.66935581     28.2225851
80       85.1748796     2123.61111     144.682954     14.3577208     0.57278725     25.3075714
120       91.0841667     2067.59259     184.682954     10.9117728     0.47716001     24.0004450
1                                             21:43 Thursday, July 29, 2019  10

The GLM Procedure
Least Squares Means

NM_kgN_ha_     GY_kg_ha_     N_supply_
Vari_t_s        LSMEAN        LSMEAN        LSMEAN     NUE LSMEAN    NUpE LSMEAN    NUtE LSMEAN

Bousselam    75.4092716    1815.43210    149.627593    12.6758996    0.50952157    24.7343494
GTAdur       78.9218580    2119.75309    145.030815    15.0283863    0.54392596    27.6676505
MBB          85.9728765    1987.65432    134.839074    14.8946760    0.62939671    23.4134459
Megress      90.7320617    2383.95062    149.234333    16.5123405    0.60955986    27.5586896
1                                             21:43 Thursday, July 29, 2019  11

The GLM Procedure

t Tests (LSD) for NM_kgN_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                          0.05
Error Degrees of Freedom           70
Error Mean Square           291.6841
Critical Value of t          1.99444
Least Significant Difference   8.0286


Means with the same letter are not significantly different.


t Grouping         Mean      N    Ann_e

A       114.873     36    2018

B       101.450     36    2016

C        31.954     36    2017
1                                             21:43 Thursday, July 29, 2019  12
```

```
The GLM Procedure

t Tests (LSD) for GY_kg_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square            251394.1
Critical Value of t           1.99444
Least Significant Difference    235.7


Means with the same letter are not significantly different.


t Grouping          Mean       N    Ann_e

A        2756.5     36    2018
A
A        2592.6     36    2016

B         881.0     36    2017
1                                              21:43 Thursday, July 29, 2019  13

The GLM Procedure

t Tests (LSD) for N_supply_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square            201.6001
Critical Value of t           1.99444
Least Significant Difference   6.6747


Means with the same letter are not significantly different.


t Grouping          Mean       N    Ann_e

A       175.790     36    2018

B       139.614     36    2016

C       118.645     36    2017
1                                              21:43 Thursday, July 29, 2019  14

The GLM Procedure

t Tests (LSD) for NUE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
```

```
Error Degrees of Freedom          70
Error Mean Square           17.49304
Critical Value of t          1.99444
Least Significant Difference   1.9662


Means with the same letter are not significantly different.


t Grouping          Mean      N    Ann_e

A       19.8730     36    2016

B       16.5022     36    2018

C        7.9583     36    2017
1                                                    21:43 Thursday, July 29, 2019  15

The GLM Procedure

t Tests (LSD) for NUpE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom          70
Error Mean Square           0.015969
Critical Value of t          1.99444
Least Significant Difference   0.0594


Means with the same letter are not significantly different.


t Grouping          Mean      N    Ann_e

A       0.74616     36    2016

B       0.68172     36    2018

C       0.29142     36    2017
1                                                    21:43 Thursday, July 29, 2019  16

The GLM Procedure

t Tests (LSD) for NUtE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom          70
Error Mean Square            16.5169
Critical Value of t          1.99444
Least Significant Difference   1.9105


Means with the same letter are not significantly different.
```

```
t Grouping          Mean       N    Ann_e

A       27.3412     36    2017
A
A       26.1109     36    2016

B       24.0785     36    2018
1                                                21:43 Thursday, July 29, 2019  17

The GLM Procedure

t Tests (LSD) for NM_kgN_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                          0.05
Error Degrees of Freedom           70
Error Mean Square            291.6841
Critical Value of t          1.99444
Least Significant Difference   8.0286


Means with the same letter are not significantly different.


t Grouping          Mean       N    Doses

A        91.084     36    120
A
A        85.175     36    80

B        72.018     36    40
1                                                21:43 Thursday, July 29, 2019  18

The GLM Procedure

t Tests (LSD) for GY_kg_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                          0.05
Error Degrees of Freedom           70
Error Mean Square            251394.1
Critical Value of t          1.99444
Least Significant Difference    235.7


Means with the same letter are not significantly different.


t Grouping          Mean       N    Doses

A        2123.6     36    80
A
A        2067.6     36    120
A
A        2038.9     36    40
```

```
1                                    21:43 Thursday, July 29, 2019  19

1                                    21:43 Thursday, July 29, 2019  20

The GLM Procedure

t Tests (LSD) for NUE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                         0.05
Error Degrees of Freedom        70
Error Mean Square         17.49304
Critical Value of t        1.99444
Least Significant Difference   1.9662


Means with the same letter are not significantly different.


t Grouping          Mean      N    Doses

A       19.0640     36    40

B       14.3577     36    80

C       10.9118     36    120
1                                    21:43 Thursday, July 29, 2019  21

The GLM Procedure

t Tests (LSD) for NUpE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                         0.05
Error Degrees of Freedom        70
Error Mean Square         0.015969
Critical Value of t        1.99444
Least Significant Difference   0.0594


Means with the same letter are not significantly different.


t Grouping          Mean      N    Doses

A       0.66936     36    40

B       0.57279     36    80

C       0.47716     36    120
1                                    21:43 Thursday, July 29, 2019  22

The GLM Procedure

t Tests (LSD) for NUtE
```

```
NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square            16.5169
Critical Value of t          1.99444
Least Significant Difference   1.9105


Means with the same letter are not significantly different.


t Grouping          Mean      N    Doses

A       28.2226     36    40

B       25.3076     36    80
B
B       24.0004     36    120
1                                            21:43 Thursday, July 29, 2019  23

The GLM Procedure

t Tests (LSD) for NM_kgN_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square           291.6841
Critical Value of t          1.99444
Least Significant Difference   9.2706


Means with the same letter are not significantly different.


t Grouping          Mean      N    Vari_t_s

A        90.732     27    Megress
A
B    A        85.973     27    MBB
B
B    C        78.922     27    GTAdur
C
C        75.409     27    Bousselam
1                                            21:43 Thursday, July 29, 2019  24

The GLM Procedure

t Tests (LSD) for GY_kg_ha_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square           251394.1
```

```
Critical Value of t          1.99444
Least Significant Difference   272.16


Means with the same letter are not significantly different.


t Grouping         Mean      N    Vari_t_s

A       2384.0     27    Megress
A
B    A       2119.8     27    GTAdur
B
B    C       1987.7     27    MBB
C
C       1815.4     27    Bousselam
1                                               21:43 Thursday, July 29, 2019  25

The GLM Procedure

t Tests (LSD) for N_supply_

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square           201.6001
Critical Value of t          1.99444
Least Significant Difference   7.7072


Means with the same letter are not significantly different.


t Grouping         Mean      N    Vari_t_s

A      149.628     27    Bousselam
A
A      149.234     27    Megress
A
A      145.031     27    GTAdur

B      134.839     27    MBB
1                                               21:43 Thursday, July 29, 2019  26

The GLM Procedure

t Tests (LSD) for NUE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                        0.05
Error Degrees of Freedom           70
Error Mean Square           17.49304
Critical Value of t          1.99444
Least Significant Difference   2.2703
```

```
Means with the same letter are not significantly different.


t Grouping          Mean      N    Vari_t_s

A        16.512     27    Megress
A
A        15.028     27    GTAdur
A
B    A        14.895     27    MBB
B
B            12.676     27    Bousselam
1                                                21:43 Thursday, July 29, 2019  27

The GLM Procedure

t Tests (LSD) for NUpE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                         0.05
Error Degrees of Freedom           70
Error Mean Square            0.015969
Critical Value of t          1.99444
Least Significant Difference   0.0686


Means with the same letter are not significantly different.


t Grouping          Mean      N    Vari_t_s

A       0.62940     27    MBB
A
B    A       0.60956     27    Megress
B
B    C       0.54393     27    GTAdur
C
C       0.50952     27    Bousselam
1                                                21:43 Thursday, July 29, 2019  28

The GLM Procedure

t Tests (LSD) for NUtE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.


Alpha                         0.05
Error Degrees of Freedom           70
Error Mean Square             16.5169
Critical Value of t          1.99444
Least Significant Difference   2.2061


Means with the same letter are not significantly different.


t Grouping          Mean      N    Vari_t_s
```

```
A       27.668     27    GTAdur
A
A       27.559     27    Megress

B       24.734     27    Bousselam
B
B       23.413     27    MBB
```

Annex 4. Results ANCOVA of GY, NUE and theirs components

```
# Import data = “Setif”
Setif <- readXL("D:\\Download\\BENCHELALI Data.xlsx", rownames=FALSE, header=TRUE, na="",
sheet="GY and DM", stringsAsFactors=TRUE)
Setif$Doses<- with(Setif, factor(Doses, levels=c('0', '40', '80', '120')))
Setif$Bloc<- with(Setif, factor(Bloc, levels=c('1', '2', '3')))
```

```
Setif2 <- readXL("D:\\Download\\BENCHELALI Data.xlsx", rownames=FALSE, header=TRUE, na="",
sheet="NupE, NUE", stringsAsFactors=TRUE)
Setif2$Doses<- with(Setif2, factor(Doses, levels=c('40', '80', '120')))
Setif2$Bloc<- with(Setif2, factor(Bloc, levels=c('1', '2', '3')))


# NAMES: "Année"   "Variétés" "Doses"   "Bloc"   "RVP"   "RFrP"   "RFnP"   "MT"   "DMST.F"
"DMS.F"   "DM.F"   "DMST.M"  "DMS.M"   "DM.M"   "GY"   "NbrS.m2"  "TGW"   "HI"


names(Setif2) : "Année"   "Variétés" "Doses"   "Bloc"   "RVP"   "RFrP"   "RFnP"   "MT"   "NM"
"NUE"   "NUpE"   "NUtE"


#DESCRIPTIVE STATISTICS DATA= Setif + Setif2

numSummary(Setif[,c("DMST.F","DMS.F","DM.F","DMST.M","DMS.M","DM.M","GY","NbrS.m2","TGW",
"HI")], groups= Setif$Variétés, statistics=c("mean", "sd", "IQR", "quantiles", "cv"), quantiles=c(0,.25,.5,.75,1))
numSummary(Setif[,c("DMST.F","DMS.F","DM.F","DMST.M","DMS.M","DM.M","GY","NbrS.m2","TGW",
"HI")], groups= Setif$Doses, statistics=c("mean", "sd", "IQR", "quantiles", "cv"), quantiles=c(0,.25,.5,.75,1))
numSummary(Setif[,c("DMST.F","DMS.F","DM.F","DMST.M","DMS.M","DM.M","GY","NbrS.m2","TGW",
"HI")], statistics=c("mean", "sd", "IQR", "quantiles", "cv"), quantiles=c(0,.25,.5,.75,1))

numSummary(Setif2[,c("NM","NUE","NUpE","NUtE")], groups= Setif2$Variétés, statistics=c("mean", "sd",
"IQR", "quantiles", "cv"), quantiles=c(0,.25,.5,.75,1))
numSummary(Setif2[,c("NM","NUE","NUpE","NUtE")], groups= Setif2$Doses, statistics=c("mean", "sd",
"IQR", "quantiles", "cv"), quantiles=c(0,.25,.5,.75,1))
numSummary(Setif2[,c("NM","NUE","NUpE","NUtE")], statistics=c("mean", "sd", "IQR", "quantiles", "cv"),
quantiles=c(0,.25,.5,.75,1))

#GLMs

GLM1= glm(DMST.F ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM1, type="II", test="F")

GLM2= glm(DMS.F~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM2, type="II", test="F")

GLM3= glm(DM.F ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
```

```
Anova(GLM3, type="II", test="F")

GLM4= glm(DMST.M ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM4, type="II", test="F")

GLM5= glm(DMS.M ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM5, type="II", test="F")

GLM6= glm(DM.M ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM6, type="II", test="F")

GLM7= glm(GY~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM7, type="II", test="F")

GLM8= glm(NbrS.m2~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM8, type="II", test="F")

GLM9= glm(TGW ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM9, type="II", test="F")

GLM10= glm(HI ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif)
Anova(GLM10, type="II", test="F")

GLM11= glm(NM ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif2)
Anova(GLM11, type="II", test="F")

GLM12= glm(NUE ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif2)
Anova(GLM12, type="II", test="F")

GLM13= glm(NUpE ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif2)
Anova(GLM13, type="II", test="F")

GLM14= glm(NUtE ~ (Variétés*Doses )   *( RVP + RFFP+ MT), family=gaussian(identity),  data= Setif2)
Anova(GLM14, type="II", test="F")
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DM.M	SS	Df	F-value	Pr(>F)		
Variétés	13993505	3	2.9740	0.0341969	*	
Doses	22901403	3	4.8672	0.0030723	**	
RVP	1117444074	1	712.4694	2.2e-16	***	
RFFP	216340431	1	137.9362	2.2e-16	***	
MT	21655004	1	13.8070	0.0003015	***	
Variétés:Doses	73245770	9	5.1890	0.000005290	***	
Variétés:RVP	30349653	3	6.4502	0.0004215	***	
Variétés:RFFP	24253817	3	5.1547	0.0021364	**	
Variétés:MT	21425826	3	4.5536	0.0045721	**	
Doses:RVP	26708148	3	5.6763	0.0011080	**	
Doses:RFFP	1585082	3	0.3369	0.7986925		
Doses:MT	2447854	3	0.5202	0.6691058		
Variétés:Doses:RVP	77327497	9	5.4781	0.000002338	***	
Variétés:Doses:RFFP	9039677	9	0.6404	0.7607270		
Variétés:Doses:MT	14597742	9	1.0342	0.4165856		
Residuals	200756461	128				
GY	SS	Df	F-value	Pr(>F)		
Variétés	2326454	3	2.9016	0.0375029	*	
Doses	1028300	3	1.2825	0.2832443		
RVP	161964978	1	606.0090	2.2e-16	***	
RFFP	10066900	1	37.6664	9.747e-09	***	

MT	13552774	1	50.7091	6.871e-11	***	
Variétés:Doses	10863488	9	4.5163	3.600e-05	***	
Variétés:RVP	7026107	3	8.7630	2.496e-05	***	
Variétés:RFFP	3897356	3	4.8608	0.0030975	**	
Variétés:MT	5096243	3	6.3560	0.0004738	***	
Doses:RVP	3555945	3	4.4350	0.0053156	**	
Doses:RFFP	856116	3	1.0677	0.3652605		
Doses:MT	1523163	3	1.8997	0.1329233		
Variétés:Doses:RVP	8977276	9	3.7322	0.0003437	***	
Variétés:Doses:RFFP	2862130	9	1.1899	0.3069388		
Variétés:Doses:MT	2998806	9	1.2467	0.2726014		
Residuals	34209919	128				
NbrS.m2	SS	Df	F-value	Pr(>F)		
Variétés	56049	3	9.7925	7.322e-06	***	
Doses	50710	3	8.8597	2.223e-05	***	
RVP	607741	1	318.5417	2.2e-16	***	
RFFP	74114	1	38.8461	6.121e-09	***	
MT	110006	1	57.6588	5.727e-12	***	
Variétés:Doses	64549	9	3.7592	0.0003179	***	
Variétés:RVP	20360	3	3.5572	0.0162570	*	
Variétés:RFFP	27841	3	4.8642	0.0030840	**	
Variétés:MT	47105	3	8.2298	4.748e-05	***	
Doses:RVP	3715	3	0.6491	0.5849183		
Doses:RFFP	16667	3	2.9119	0.0370101	*	
Doses:MT	6429	3	1.1233	0.3422251		
Variétés:Doses:RVP	73746	9	4.2948	6.801e-05	***	
Variétés:Doses:RFFP	32533	9	1.8946	0.0582823	.	
Variétés:Doses:MT	45392	9	2.6435	0.0076797	**	
Residuals	244210	128				
TGW	SS	Df	F-value	Pr(>F)		
Variétés	1304685	3	5.1635	0.0021126	**	
Doses	1066226	3	4.2198	0.0069886	**	
RVP	61551308	1	730.7971	2.2e-16	***	
RFFP	33573138	1	398.6130	2.2e-16	***	
MT	480188	1	5.7013	0.0184146	*	
Variétés:Doses	2753760	9	3.6328	0.0004575	***	
Variétés:RVP	867795	3	3.4344	0.0190138	*	
Variétés:RFFP	482151	3	1.9082	0.1315225		
Variétés:MT	6277	3	0.0248	0.9946797		
Doses:RVP	701451	3	2.7761	0.0439929	*	
Doses:RFFP	374188	3	1.4809	0.2228439		
Doses:MT	6454	3	0.0255	0.9944567		
Variétés:Doses:RVP	1829013	9	2.4129	0.0145691	*	
Variétés:Doses:RFFP	971910	9	1.2822	0.2527080		
Variétés:Doses:MT	16892	9	0.0223	0.9999994		
Residuals	10780786	128				
HI	SS	Df	F-value	Pr(>F)		
Variétés	1698.9	3	18.0154	8.164e-10	***	
Doses	85.6	3	0.9082	0.43915		
RVP	49.9	1	1.5889	0.20977		
RFFP	880.3	1	28.0044	5.093e-07	***	
MT	609.2	1	19.3793	2.237e-05	***	

Variétés:Doses	360.6	9	1.2746	0.25685		
Variétés:RVP	142.5	3	1.5114	0.21472		
Variétés:RFFP	93.6	3	0.9927	0.39853		
Variétés:MT	176.9	3	1.8755	0.13698		
Doses:RVP	96.6	3	1.0244	0.38417		
Doses:RFFP	256.5	3	2.7197	0.04726	*	
Doses:MT	218.8	3	2.3200	0.07843	.	
Variétés:Doses:RVP	147.6	9	0.5217	0.85666		
Variétés:Doses:RFFP	162.7	9	0.5751	0.81553		
Variétés:Doses:MT	173.5	9	0.6134	0.78390		
Residuals	4023.6	128				
NM	SS	Df	F-value	Pr(>F)		
Variétés	370	3	0.3229	0.8087850		
Doses	10528	2	13.7657	0.0000055427	***	
RVP	85515	1	223.6219	2.2e-16	***	
RFFP	4420	1	11.5576	0.0009842	***	
MT	11189	1	29.2590	0.0000004636	***	
Variétés:Doses	11495	6	5.0097	0.0001663	***	
Variétés:RVP	11608	3	10.1180	0.0000074631	***	
Variétés:RFFP	3884	3	3.3854	0.0212611	*	
Variétés:MT	5743	3	5.0058	0.0028727	**	
Doses:RVP	1619	2	2.1163	0.1260680		
Doses:RFFP	1372	2	1.7942	0.1717979		
Doses:MT	669	2	0.8753	0.4200217		
Variétés:Doses:RVP	4317	6	1.8815	0.0917845	.	
Variétés:Doses:RFFP	857	6	0.3733	0.8943161		
Variétés:Doses:MT	503	6	0.2191	0.9698090		
Residuals	36711	96				
NUE	SS	Df	F-value	Pr(>F)		
Variétés	184.50	3	3.0851	0.030912	*	
Doses	1395.82	2	35.0106	3.812e-12	***	
RVP	968.40	1	48.5797	4.000e-10	***	
RFFP	753.50	1	37.7992	1.790e-08	***	
MT	27.79	1	1.3941	0.240631		
Variétés:Doses	473.04	6	3.9550	0.001409	**	
Variétés:RVP	825.64	3	13.8060	1.475e-07	***	
Variétés:RFFP	160.54	3	2.6845	0.050938	.	
Variétés:MT	322.27	3	5.3889	0.001801	**	
Doses:RVP	41.47	2	1.0403	0.357305		
Doses:RFFP	219.83	2	5.5138	0.005410	**	
Doses:MT	145.58	2	3.6515	0.029622	*	
Variétés:Doses:RVP	161.66	6	1.3516	0.242135		
Variétés:Doses:RFFP	97.05	6	0.8114	0.563605		
Variétés:Doses:MT	72.34	6	0.6048	0.725872		
Residuals	1913.69	96				
NUpE	SS	Df	F-value	Pr(>F)		
Variétés	0.08818	3	1.1452	0.33489		
Doses	0.88364	2	17.2148	0.00000040830	***	
RVP	0.65226	1	25.4144	0.00000217732	***	
RFFP	1.05718	1	41.1913	0.00000000523	***	
MT	0.04306	1	1.6777	0.19834		
Variétés:Doses	0.47522	6	3.0860	0.00832	**	

Variétés:RVP	0.90553	3	11.7609	0.00000125253	***	
Variétés:RFFP	0.22312	3	2.8978	0.03904	*	
Variétés:MT	0.37688	3	4.8949	0.00329	**	
Doses:RVP	0.03426	2	0.6674	0.51538		
Doses:RFFP	0.00701	2	0.1365	0.87259		
Doses:MT	0.01398	2	0.2723	0.76220		
Variétés:Doses:RVP	0.16649	6	1.0812	0.37923		
Variétés:Doses:RFFP	0.05429	6	0.3525	0.90683		
Variétés:Doses:MT	0.02111	6	0.1371	0.99107		
Residuals	2.46385	96				
NUtE	SS	Df	F-value	Pr(>F)		
Variétés	253.81	3	4.9044	0.0032520	**	
Doses	311.33	2	9.0239	0.0002563	***	
RVP	238.76	1	13.8406	0.0003351	***	
RFFP	11.28	1	0.6539	0.4207195		
MT	8.19	1	0.4749	0.4924055		
Variétés:Doses	22.71	6	0.2194	0.9697104		
Variétés:RVP	138.83	3	2.6827	0.0510494	.	
Variétés:RFFP	23.42	3	0.4526	0.7160446		
Variétés:MT	42.60	3	0.8231	0.4842658		
Doses:RVP	73.11	2	2.1191	0.1257300		
Doses:RFFP	363.82	2	10.5451	0.00007245	***	
Doses:MT	224.80	2	6.5159	0.0022207	**	
Variétés:Doses:RVP	48.54	6	0.4690	0.8297873		
Variétés:Doses:RFFP	111.27	6	1.0750	0.3829157		
Variétés:Doses:MT	85.97	6	0.8306	0.5490996		
Residuals	1656.05	96				