AMERICAN UNIVERSITY OF BEIRUT

EFFECT OF EXCESS NITROGEN FERTILIZATION ON TRITICALE PRODUCTION UNDER RAINFED AND SUPPLEMENTAL IRRIGATION CONDITIONS

by
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ABSTRACT

OF THE THESIS OF

Mudhafar Ameen Abu-Altemen for Master of Science
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Title: Effect of Excess Nitrogen Fertilization on Triticale Production Under Rainfed and Supplemental Irrigation Conditions

Triticale (*Triticosecale Wittmack)* is an annual human-made cereal that belongs to the family Poaceae. It is an important crop in various regions of the world, known for its high forage potential, with little known about its water and nutrients requirements. This research presents the results of two adjacent field experiments that were conducted in the fall and spring of 2020-2021 at the Advancing Research Enabling Communities Center (AREC) in the Beqaa plain at the American University of Beirut, Lebanon to examine the effect of various rates of nitrogen fertilizer on growth parameters and yield quantity and quality of triticale under rainfed and supplementary irrigation. Each of the field experiments consisted of seven fertilizer treatments (0, NPK at 100 kg/ha, nitrogen at 40, 80, 120, 160, and 200 kg/ha). Supplementary irrigation was applied three times during the growing season starting 148, 157, and 172 days after planting (DAP). Data collected were plant height, shoot number, shoot fresh and dry weight, grain yield, spike number and weight, hay dry weight, and various grain parameters such as protein, fiber, starch, ash, fat, moisture and morphology.

Results showed that supplementary irrigation increased crop height, shoot fresh weight, and grain yield, compared to the rain-fed regardless of NPK or nitrogen applications. While it did not increase shoot dry weight in comparison to the rainfed. Neither nitrogen treatments nor supplementary irrigation alone enhanced hay dry weight, compared to rainfed. The addition of nitrogen at all tested rates had no significant effect on triticale shoot dry weight and grain yield under both irrigation systems. A higher yield was obtained under supplementary irrigation than in the rainfed system regardless of the nitrogen application. The average grain yield of triticale under supplementary irrigation was 5.8 tons/ha while it was 4.9 tons/ha under rainfed conditions. Spike number and weight with or without nitrogen fertilizers were higher under supplementary irrigation than in the rainfed system. Grain protein content under rainfed conditions with or without nitrogen was higher than supplementary irrigation. While the grain starch content under supplementary irrigation with or without nitrogen was higher than the rain-fed. The addition of nitrogen fertilizer did not enhance grain starch content. Results show a negative relationship between grain starch and protein content under both irrigation systems. Supplementary irrigation with or without nitrogen did not increase the grain ash content of grain in comparison to all rain-fed treatments. Application of nitrogen at all tested rates increased the grain moisture content under rain-fed compared to the supplementary irrigation. Morphological measurements of

supplementary irrigation alone or with nitrogen were higher than under rainfed conditions. Nitrogen at all tested rates increased the grain area of triticale under supplementary irrigation, compared to the same treatments under rainfed conditions. Supplementary irrigation alone significantly increased the grain area and grain length and width in comparison to all nitrogen treatments under both irrigation systems. Results showed that supplementary irrigation alone or with NPK resulted in higher plant biomass and yield (quantity and quality) than other nitrogen fertilizers under rainfed conditions.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS 1

ABSTRACT 2

ILLUSTRATIONS 8

TABLES.. 11

ABBREVIATIONS 15

INTRODUCTION 17

LITERATURE REVIEW.. 20

2.1. Triticale 20

2.1.1 Historical overview 20
2.1.2 Classification.. 23
2.1.3. Importance of triticale in the world.................................. 24
2.1.4. Uses of triticale 25
2.1.5. Nutritional value 28
2.1.6. Yield... 29
2.1.7. Cost and economical value 30
2.1.8 Triticale growth and development 31
2.1.9 Weather conditions 31
2.1.10. Soil conditions.. 32
2.1.11. Triticale cultivation 32
2.1.12. Seed preparation and rate 33
2.1.13 Sowing preparation 34
2.1.14. Triticale pests 35

2.2. Plant nutrition requirement & nitrogen fertilization 36

2.2.1. Nutrition requirements overview 36
2.2.2. Nitrogen overview........ 37
2.2.3. Nitrogen fertilizer application........ 40
2.2.4. Impact of nitrogen deficiency on triticale 42
2.2.5. Impact of nitrogen excess on triticale 43

2.3. Water requirement........ 44

2.3.1. Soil moisture 45
2.3.2. Cultivating triticale under rainfed conditions 45
2.3.3. Cultivating triticale under supplemental irrigation system conditions 47

2.4. Grain content........ 47

2.4.1. Comparison between NIRS technique and wet chemistry for analyzing grain content of agricultural products 48
2.4.2. Impact of fertilization program on the grain content of triticale........ 50
2.4.3. Impact of Watering systems on the grain content of triticale 50

2.5. Grain morphology........ 51

MATERIALS AND METHODS........ 54

3.1. Soil analysis 54

3.2. Sources of triticale seeds........ 54

3.3. Types of chemical fertilizers........ 55

3.4. Experimental description 55

3.5. Experimental design........ 55

3.6. Land preparation 57

3.7. Sowing triticale seeds........ 58

3.8. Nitrogen fertilization treatments........ 60

3.9. Irrigation system 62

3.9.1. Estimating soil moisture..62
3.9.2. Supplemental irrigation system..65

3.10. Data collection..67

3.11. Grain content analysis..72

3.12. Grain morphology measurements...73

3.13. Statistical analysis..74

RESULTS AND DISCUSSION...75

4.1. Soil analysis..75

4.2 Irrigation applications...76

4.3 Data collection..77

4.4 Results and discussions..78

4.4.1 Effect on plant height, fresh weight, and dry weight....................................78
4.4.2 Effect on grain weight..86
4.4.3 Effect on grain weight regardless of the treatments of fertilization..............89
4.4.4 Effect on spike weight and spike number per square meter..........................89
4.4.5 Effect on hay dry weight...92
4.4.6 Effect on grain content..94
4.4.7 Effect on grain morphology...107

SUMMARY, CONCLUSION, AND RECOMMENDATIONS 117

5.1 Summary...117

5.2 Conclusion..117

5.3 Recommendation..117

CHAPTER 6 119

APPENDIX 119

6.1 Tables of data results 119

6.1.1Effect on plant height, fresh weight, and dry weight 119

6.1.3 Effect on grain weight regardless of the treatments of fertilization 123

6.1.4 Effect on spike weight and spike number per square meter 124

6.1.5 Effect on dry hay weight per square meter 125

6.1.6 Effect on grain content 125

6.1.7 Effect on grain morphology 128

6.2 Syntax code of SPSS 136

BIBLIOGRAPHY 137

ILLUSTRATIONS

Figure

1. Google earth view of AREC 19
2. Head (ear) shapes of durum wheat (left), triticale, rye (right) 22
3. Grains of (A) common wheat, (B) durum wheat, (C) triticale and (D) cereal rye 23
4. Measuring seed rate/area 34
5. Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco 41
6. Field map description 56
7. Primary tillage with a moldboard plow 58
8. Planting triticale with agricultural grain drill 59
9. Rolling the field after sowing with a Cambridge Roller 60
10. Accumulative precipitation of rain for two years 63
11. Accumulative precipitation of rain before and after crop planting date 64
12. Sprinkler, main line, and lateral line distribution chart 66
13. Cutting ears of triticale 68
14. The collected spikes 69
15. Agricultural thresher machine 70
16. Seed cleaner machine 71
17. Seed counter machine 72
18. Seed scanner 73
19. Average of plant height (cm) of triticale under rainfed (R) and supplemental irrigation (S) systems after (100 DAP) ± SE, (n=80 plants) 82
20. Average of plant height (cm) of triticale under rainfed (R) and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants) 82
21. Average of plant height (cm) of triticale under rainfed (R) and supplemental irrigation (S) systems after (225 DAP) ± SE, (n=80 plants) 83

22. Average of fresh weight (g) of triticale) under rainfed (R) and supplemental irrigation (S) systems after (170 DAP) ± SE, (n= 80 plants)............................. 83

23. Average of dry weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems after (100 DAP) ± SE, (n= 80 plants)............................. 84

24. Average of dry weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants)............................... 84

25. Average of dry weight of triticale regardless the watering system after (100 DAP) ± SE, (n= 160 plants).. 85

26. Average of grain weight (g) of triticale per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)... 88

27. Average of thousand grain weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4,000 seeds) 88

28. Average of spike weight (g) of triticale per square meter, under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)... 91

29. Average of spike number of triticale per square meter, under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)... 91

30. Average of hay dry weight (g) of triticale stem per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)............................. 93

31. Average of grain protein content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds) 95

32. Average of grain starch content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE (n=4,000 seeds) 97

33. Average of grain crude fiber content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE (n=4,000 seeds) 99

34. Average of grain ash content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 101

35. Average of grain fat content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4,000 seeds)... 103

36. Average of grain moisture (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 106

37. Average of grain area (mm^2) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 109

38. Average of grain perimeter (mm) of triticale, (n=1000 seed ×4 replicates) ± SE, under rainfed (R) and supplemental irrigation (S) systems 111

39. Average of grain length (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 113

40. Average of grain width (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=1000 seed ×4 replicates)................................. 115

TABLES

Table

1. Taxonomical classification of triticale 24

2. Major triticale growing countries in the world in 2019 25

3. Methane yield that was derived from many crops 28

4. Comparative constitution of triticale, maize, and wheat grain 29

5. Average grain yield for winter wheat and triticale in six regions of Poland 31

6. Most common nitrogen fertilizer products 39

7. Nitrogen requirements for cereal crops at different combinations of yield and grain protein at maturity, and the corresponding N required at anthesis 42

8. Influence of different soil nitrogen content for two triticale breeding form for many traits 43

9. Comparison of grain yield between barely, wheat, and triticale 45

10. Details of the analysis and methods used 49

11. Mean results of nutritive components (g/kg) by using NIRS technique and wet chemistry methods 50

12. Different protein ratios under different combined N+P levels for different crops cultivars 50

13. Mean squares of hundred-grain weight and grain length and width of rice 53

14. Treatments and their corresponding replicates 57

15. Nitrogen requirements for cereal crops at various combinations of yield 61

16. Fertilizers treatments and their rates 62

17. The ratios of the soil moisture by mass in different depths, and in different dates and irrigation dates after planting 64

18. Information that was related soil moisture at depth 30cm and 50cm, precipitation, and other parameters resulting in accounting soil moisture by mass 65

19. Summary of soil analysis results 76

20. Ratio of nitrogen-nitrate and total nitrogen in the soil 76

21. Nutrient range in soils, mg/kg 76

22. Summary data of precipitation from rain (R) and supplemental (S) irrigation system 77

23. Summary data of precipitation (mm) from rain (R) and supplemental (S) irrigation days after planting (DAP) 78

24. Summary data collection combined with date and quantity of precipitation from the rain and supplemental irrigation system. 78

25. Average of plant height (cm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 80 plants) 119

26. Average plant height (cm) of triticale regardless the watering system after (100 DAP) ± SE, (n=160 plants) 120

27. Average of dry weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=80 plants) 120

28. Average of dry weight of triticale (g) regardless of the watering system at first data collection ± SE, (n=160 plants) 120

29. Average of fresh weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants) 121

30. Average of grain weight (g) of triticale per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2) 121

31. Average of thousand grain weight (g) of triticale under rainfed ® and supplemental irrigation (S) systems ± SE, (n=4,000 seeds) 122

32. Estimating grain weight (kg) of triticale for one-dunum and one-hectare under supplemental (S) irrigation system 122

33. Estimating grain weight (kg) of triticale for one-dunum and one-hectare under rainfed (R) conditions 123

34. Estimating grain weight (kg) of triticale under rainfed (R) and supplemental irrigation (S) systems regardless of nitrogen fertilizer applications 123

35. Average of spike weight (g) of triticale per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2) 124

36. Average of spike number of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2) 125

37. Average of dry hay weight (g) of triticale stem per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2) 125

38. Average of grain protein content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds) 125

39. Average of grain starch content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds) 126

40. Comparison between protein and starch grain content of triticale under rainfed and supplemental irrigations systems 126

41. Average of grain crude fiber content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds) 127

42. Average of grain ash content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 127

43. Average of grain fat content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 128

44. Average of grain moisture (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 128

45. Average of grain area (mm^2) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 129

46. Average of grain area (mm^2) and grain weight (g) per m^2 of triticale under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds) and (4 m^2), respectively 129

47. Average of grain area (mm^2) and thousand grain weight (g) of triticale, under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds)............ 130

48. Datasets from previous experiments reporting average grain weight and grain area of wheat 130

49. Average of grain perimeter (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 131

50. Average of grain perimeter (mm) and grain weight (g) per square meter of triticale, under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds) and (4 m^2), respectively 131

51. Average of grain perimeter (mm) and thousand grain weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds)... 132

52. Average of grain length (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 132

53. Average of grain length (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively 133

54. Average of grain length (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively 133

55. Range of kernel shape of Ethiopian durum wheat 133

56. Average of grain width (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds).. 134

57. Average of grain width (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively 134

58. Average of grain width (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems , (n=4,000 seeds and 4 m^2), respectively........ 135

59. Comparison of grain measurements and thousand grain weight under three cultivation treatments........ 135

ABBREVIATIONS

&	And
°C	Degrees Celsius
$	Dollar
/	Per
%	Percentage of Hundred
>	Greater than
<	Less than
α	Alpha (significant level)
#	Number
ai	Active Ingredient
FAO	Food and Agriculture Organization of the United Nations
MENA	Middle East/North Africa
AUB	American University of Beirut
AREC	Advancing Research Enabling Communities Center
FAFS	Faculty of Agricultural and Food Sciences
Mha	Million hectares
CIMMYT	International Maize and Wheat Improvement Center
hg/ha	Hectogram per hectare =100 gram/ 10,000m^2
Mtons	10 million or mega tons of oil equivalent
t/ha	Tonnes per hectare
Kg/ha	Kilograms per hectare
€/ha	Euro per hectare
pH	potential of hydrogen
EC	Electrical conductivity
dsm	Decisiemens per meter
NH_3	Synthetic ammonia
HNO_3	Nitric Acid
NH_4NO_3	Ammonium nitrate
$(NH_4)_2SO_4$	Ammonium sulfate
NPK	nitrogen (N), phosphorus (P), and potassium (K)
NH_4^+	Ammonium
NO_3^-	Nitrate
CH_4N_2O	Urea
p	P- value
ADF	Acid detergent fiber
NDF	Neutral detergent fiber
NIRS	Near-infrared spectroscopy
CP	crude protein
N	Nitrogen

P	Phosphorous
m	meter
cm	centimeter
mm	millimeter
$CaCO_3$	Calcium carbonate
LEAF	Laboratories for the Environment, Agriculture, and Food
M	mole
KCl	Potassium chloride
RCBD	Randomized complete block design
Control	Without addition any fertilizer
NPK	nitrogen (N), phosphorus (P), and potassium (K) 100 kg/ha
N-40	Granular nitrogen fertilizer 40 kg/ha
N-80	Granular nitrogen fertilizer 80 kg/ha
N-120	Granular nitrogen fertilizer 120 kg/ha
N-160	Granular nitrogen fertilizer 160 kg/ha
N-200	Granular nitrogen fertilizer 200 kg/ha
m^3/hr	Cubic meter per hour
"	One inch = 19 mm
3x	3 times
ICARDA	International Center for Agricultural Research in the Dry Areas
ANOVA	Analysis of Variance
SE	Standard error
n	Sample size
µS/cm	Micro-second per centimeter
DAP	Days After Planting
mg/kg	Milligram per kilogram
ppm	Part per million
R	Rainfed conditions
S	Supplementary irrigation
mm^2	Square millimeter
DNA	Deoxyribonucleic Acid
dS/m	Deci Siemens per meter
du	Dunum
et al.	et alia (means “and others”)
etc	et cetera (means “and so forth”)
ha	Hectare
g	Gram
K	Potassium
Kg	Kilogram
l	Liter

CHAPTER 1

INTRODUCTION

According to the World Bank, food production must increase by 70% to feed the world. This is a major challenge considering water paucity and the sustainability of resources. Climate change and global warming, as evidenced by variable precipitation and frequent droughts, will further impact water availability and crop productivity. Changes in climate that reduce precipitation will have catastrophic effects on food security. One of the most affected areas in the country is the Beqaa region, host the most significant agricultural activity in Lebanon. Accordingly, it is imperative that we introduce new grain crops that are adapted to climate change and contribute to the sustainability of rural livelihoods and environmental sustainability, especially in semi-arid regions. One of the most promising crops is triticale.

Triticale (*x Triticosecale Wittmack)* is a man-made hybrid, a cross of female parent wheat (*Triticum* spp.) and male parent rye (*Secale cereal*e L). It combines favorable traits from both crops such as growth and vigor, cold tolerance, and high protein (Gupta & Priyadarshan, 1982), but with has a greater drought, saline, and disease resistance than wheat and rye. Both forage and grain types of triticale are grown, but it is primarily used as a feed for animals (Myer *et al*., 2004; Naeem *et al*., 2002). There is a misconception that triticale does not contribute to food security. It is true that triticale as human food is still minor, but it is widely used as animal feed. The importance of triticale is the ability to adapt to multiple biotic and abiotic stresses and could be planted in marginal lands as a resilient rainfed crop. It's grown in over 40 countries around the world. According to FAO (2019), the main producer countries of triticale is Poland, Germany, France, China, and Belarus. While only Algeria and Tunisia are the main producers in the MENA region. According to our knowledge, triticale is not grown in Lebanon.

Water and nitrogen are the most limiting resources for grain production in the MENA region. Both resources are overused in arable lands, and they are no longer sustainable. Rainfall patterns are changing across the world, and for MENA region, droughts will be more frequent and severe. Accordingly, irrigation water will be highly needed than before to maintain production. The Beqaa plain is the leading county for rainfed cereal production in Lebanon. It is located in a semi-arid region where mean rainfall does not exceed 500 mm/year during the winter season. The past decade has seen a substantial decrease in precipitation: records reveal that the region's heavily exploited groundwater has suffered an alarming decline of 15-20 meters in groundwater levels over the last five years alone. In addition, nearly half of the Beqaa plain lacks sustainable water sources for irrigation. Another critical challenge is the threat to water quality from the excessive use of agrochemicals such as nitrogen. Many studies showed that proper application of nitrogen is an important indicator of the environmental impact on the production of triticale. The goals of this study is to test the impact of nitrogen fertilization at various rates on triticale growth under supplementary and rainfed conditions as well their impact on the yield of grain and protein and its composition in winter triticale grain. We believe that triticale has a potential to displace certain rainfed crops in Lebanon and could be an inspiring option as a crop capable of withstanding erratic climates and increasingly marginal soils. The work described herein was conducted at the Advancing Research Enabling Communities Center (AREC) in the Beqaa plain at the American University of Beirut, Lebanon (Figure 1).

Figure 1. *Google earth view of AREC*

CHAPTER 2

LITERATURE REVIEW

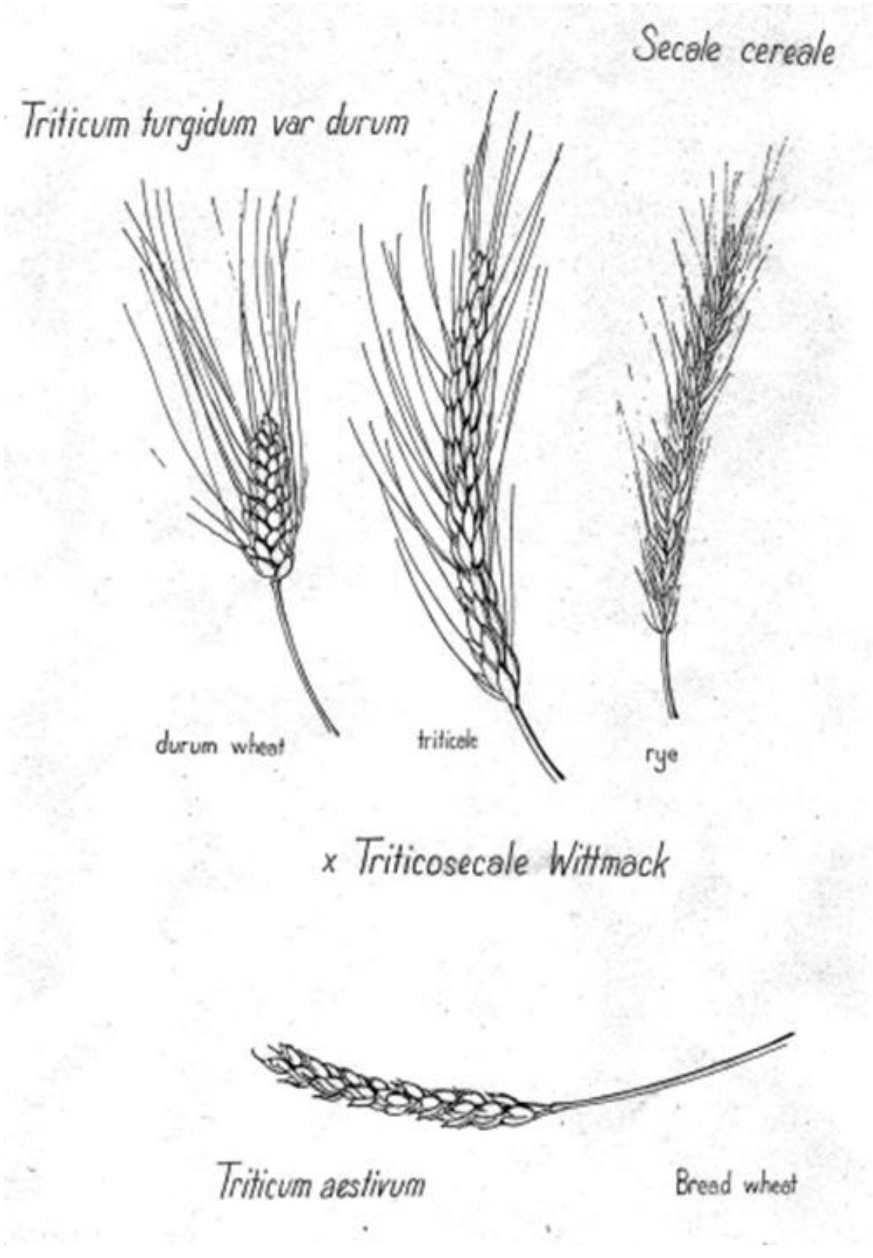
2.1. Triticale

2.1.1 Historical overview

Triticale (× *Triticosecale Wittmack*) is the first successful human-made cereal grain in the world (Figure 2 &Figure 3). A cross between durum wheat and rye, getting half its name from each parental genus. Triticale was developed by crossing male parent rye (*Secale cereale*) and female parent wheat (*Triticum* spp.*)* by Wilson in Scotland 1876. The goal was to produce a new crop that combines the high yield potential and good grain quality of wheat (Baking quality) and the resistance/tolerance to the biotic and abiotic factors of rye including adaptability to poor soils, drought, cold hardiness, disease resistance, and low-input requirements of rye. Wilson (1875) produced sterile triticale because there were dysfunctional pollen grains. After that, the German breeder Rimpau (1891) reported the developed the first triticale. However, it was till the 1970s when the first commercially triticale variety was released in Europe. Triticale variants show amphiploidy regarding wheat (AABBDD) and rye (RR) genomes (Ammar *et al*., 2004). Stable tetraploid, 20 hexaploid (AABBR/D), and octoploid (AABBDDRR) triticale cultivars had been bred. Primary triticale cultivars are produced by fertilizing hexaploid wheat plants with diploid rye pollen. Triticale cultivars are classified by the conditions required to progress from the vegetative to reproductive state: winter triticale cultivars need cold treatment while spring triticale cultivars do not, and facultative triticale cultivars have intermediary cold treatment needs (Salmon *et al*., 2004).

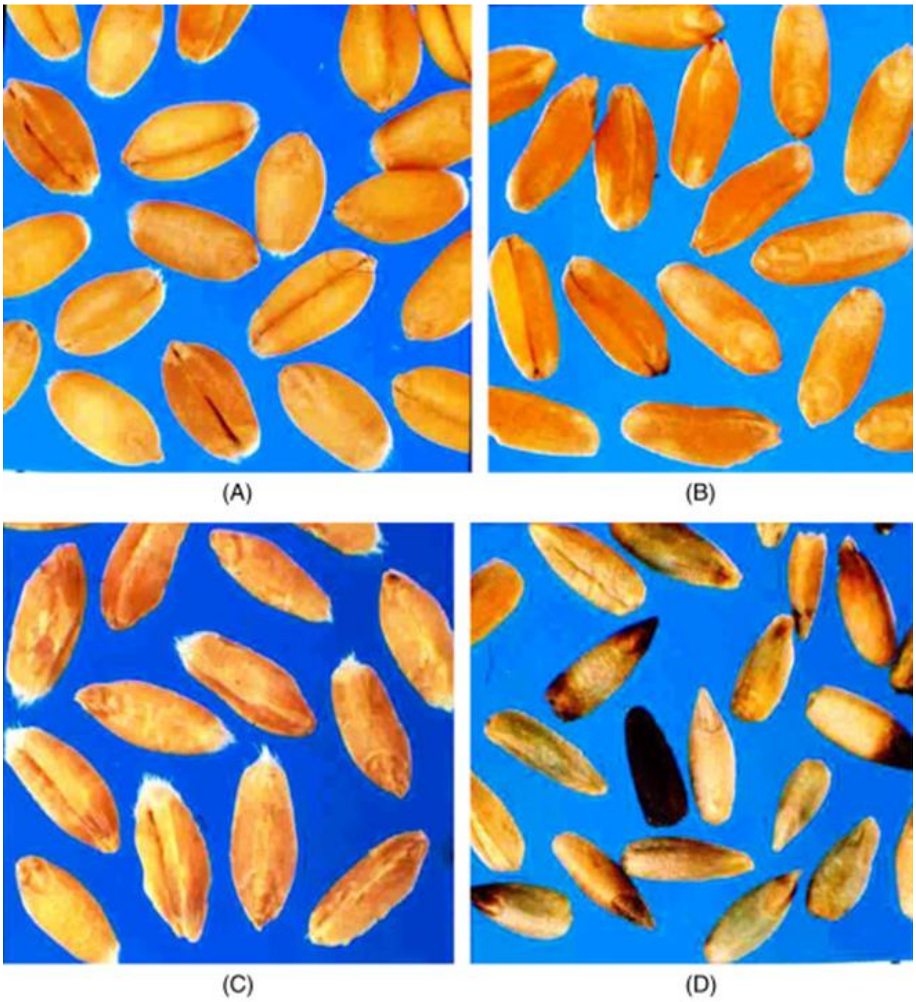
Naturally occurring hybrids of wheat and rye were first recorded at the Agricultural Experimental Station in Saratov, Russia, all being male sterile in 1918. This gave Meister and his group (1921) rich raw material (thousands of plants) to start with an extensive botanical, cytological and agronomical categorization of wheat-rye hybrids between 1918 and 1934. Studies of the wheat-rye hybrid resumed by Oehler (1935) in Germany and Muntzing (1936) in Sweden. It was till 1950s when the Hungarian plant breeders succeeded in producing the first commercially available cultivars of triticale No. 57 and Triticale No. 64. Yet, both verities were commercially released in 1968. In 1969, around 40,000 ha of Hungarian lands were planted with triticale (Ammar *et al.*, 2004) . Today triticale is grown on over 3 Mha worldwide in 27 countries (FAO, 2019). The International Maize and Wheat Improvement Center (CIMMYT) is considered one of the leaders in triticale research and improvement. Funded by Rockefeller foundation and Canadian government, CIMMYT established a joint triticale breeding program with the University of Manitoba in 1971. The aim of this program was to produce a new crop that gives higher yield than barley, wheat and oat. The first significant discovery appeared with the establishment of a new line called Armadillo. This line made a significant contribution to triticale improvement worldwide. It was the first triticale recognized to have a 2D (2R) chromosome substitution (D-genome chromosome substitution for the respective R homeologue). The crop was over-valued to farmers as a ‘miracle crop’ because of powerful improvements in triticale germplasm (Wolff, 1976). By the end of 1980s, data from international yield trials exhibited that completed hexaploid triticale (AABBRR genomic representation) was agronomically excellent to 2D(2R) substituted hexaploid types, especially under marginal growing conditions. Therefore, triticale germplasm at CIMMYT was gradually changed towards complete R genome types to be adapted for the marginal conditions better than before (Mergoum *et al.*, 2004). According to CIMMYT there are over 200 cultivars in the world. Today, CIMMYT has been regarded as a principal supplier of improved spring triticale germplasm for many national agricultural research systems globally (Mergoum *et al*., 2004).

Figure 2. *Head (spike) shapes of durum wheat (left),* ***triticale****, rye (right)*



Source: (Morrison & Wrigley, 2004)

Figure 3. *Grains of (A) common wheat, (B) durum wheat, (C)* ***triticale*** *and (D) cereal rye*



Source: (Morrison & Wrigley, 2004)

2.1.2 Classification

Triticale belongs to subtribe Triticaneae of the tribe Triticeae. The current-name of triticale emanated from the parental genera's scientific name, which was used by the Austrian agronomist *Erich Tschermak von Seysenegg*. Williams (1995), and Morrison and Wrigley (2004) declared the taxonomic classification of triticale is shown in Table 1.

Table 1. *Taxonomical classification of triticale*

Taxonomic Ranks	Name
Kingdom	Plant
Family	Grass family (Poaceae)
Subfamily	Poideae
Tribe	Triticeae
Subtribe	Triticanea
Genus and species	x Triticosecale sp

2.1.3. Importance of triticale in the world

According to FAO (2019), Poland, China, Germany, France, and Belarus are by far the world's largest producers and exporters of forage triticale (Table 2). There is also a significant production in Canada and United States. In the MENA region, triticale is well established in Tunisia and Algeria, and it is at the introduction phase in other African or Middle Eastern countries. The average grain yield is around 3.6 t/ha (FAO, 2019). In Lebanon, triticale crop is not a common crop. Yet, one study by (Saha *et al*., 1982) revealed that varieties IAKLA, CAL, 14920 and Drira-461are among the 42 varieties that were tested and could be grown in Lebanon.

Table 2. *Major triticale growing countries in the world in 2019*

Country	Area harvested (ha)	Average Yield (hg/ha)*	Average yield (ton/ha)
Poland	1314790	34212	3.4212
Belarus	453887	28871	2.8871
Germany	358200	61276	6.1276
France	305220	53780	5.378
Spain	250780	23924	2.3924
China	193787	20873	2.0873
Russia	135649	26236	2.6236
Turkey	64093	33559	3.3559
Belgium	6060	66122	6.6122
Tunisia	13000	23846	2.3846
Algeria	30	20667	2.0667

* hg/ha= Hectogram per hectare =100 gram/ 10,000m^2

2.1.4. Uses of triticale

The uses of triticale are largely mediated by its nutritional composition that is similar to wheat than rye.

2.1.4.1. Triticale for human consumption

The utilization of triticale as human food is still ambiguous; it is not used in baking industry at the international level. Although triticale contains lass gluten than wheat flour, triticale dough has more stickiness than wheat dough. Tests showed that triticale dough absorbed less water, had shorter development times, was less tolerant to mixing and had lower dough strength than wheat-based doughs. Thus, it should be mixed with wheat flour to make bread and pastries. However, triticale varieties with soft grain textures are suitable for making wafers, biscuits, cakes, and muffins (Tiefenbacher, 2017). Currently, it is widely used a forage crop for livestock Consumption since it is rich in protein and lysine than wheat.

2.1.4.2. Triticale for animal consumption

Triticale is primarily used as livestock and poultry feed in various forms such as grain, forage, silage, hay and straw. It approximately equal importance to other cereal crops in the nutrition of livestock. Triticale is fundamentally an energy source, having moderate protein content with a high ratio of starch and other carbohydrates, supplying livestock animals with great energy content. Regarding energy value, triticale is higher than barley in animal feed rations and equal to or better than wheat or maize in pig and poultry diets. In dairy feeding, triticale is considered a superior forage crop comparing with barely because it has high, quickly metabolized energy, tastiness, and ease of milling (Jondreville *et al.,* 2007). It is currently used as poultry feed due to high phosphorus concentration which reduces the need for mineral supplementation and consequently leads to lower phosphorus excretion by the birds (Jondreville *et al.*, 2007).

2.1.4.2.1. Nutrient composition of triticale forage

Keles *et al*. (2016) found that nutrient content, especially amino acid levels, and digestibility are the major factors that should be examined when selecting a triticale cultivar for use as animal feed. Triticale is better than rye and barely, but it is lower than wheat and oat concerning the nutritional value of forage. Triticale as a feed supply for ruminants has been investigated. Lema *et al*., (2007) found that winter triticale for meat goats was superior to fescue both in forage quality and nutrient content, as well as ability to promote live weight gain of goat. Keles *et al.*, (2016) evaluated the nutritional value of triticale forage for lambs. The results proved that the nutritional value of the cereal forages was different at the various stages of triticale development during the growing levels. The favorite feed base regarding lambs was in the early vegetative stage. Hence, the researchers concluded that the cereal species at the growth stage, which is coming after ear emergence and before the milk stage, are not valuable forage feeds because these cereals have low nutritive quality.

2.1.4.3. Triticale for biofuels

Biofuels that are produced from organic matter are a possible alternative green fuel. The first-generation biofuels such as bioethanol produced from cereals is the most commonly used liquid biofuel (Demirbas, 2007). Any biological substance that contains enough sugar (such as glucose or fructose) or carbohydrates (e.g., cellulose or starch) can become a source for the manufacture of ethanol. Due to the high starch content in cereal grain, triticale is considered a viable bioethanol feedstock. Starch is converted to simple sugars by saccharification. The saccharification is done by adding an enzyme suitable for the processes or through the inherent endogenous enzyme activity of the grain (Rosenberger, 2002).

2.1.4.4. Triticale for biogas

Renewable fuel and electric energy production depend on anaerobic digestion technology. In Europe, in late 2011, the production of primary energy from biogas exceeded 10 million or mega tons of oil equivalent (Mtons) per year, with an increment of approximately 20% compared to 2009 (EurObserv, 2012). Many studies compared the cost of triticale for biogas compared to many crops and concluded that triticale for biogas production had been economically feasible. For instance, Markou *et al.* (2017) found that there is a high methane yield derived from triticale (Table 3) and the cost of biogas production from triticale is cheaper than other crops.

Table 3. *Methane yield that was derived from many crops*

Energy Crop	CH_4 (m^3/ha)
Triticale	3500
Maize	5300
Alfalfa	3000
Sunflower	2600
Clover	2100
Barley	1400
Wheat	1400

2.1.5. Nutritional value

2.1.5.1. Nutrient composition of triticale grain

According to (Barneveld & Cooper, 2002; Choct & Hughes, 1999; Council, 1998, 2000; Gursoy & Yilmaz, 2002; Myer *et al.*, 1990; Radecki & Miller, 1990) the ratio of crude protein, lysine, crude fiber, acid detergent fiber, and neutral detergent fiber in the triticale grain is more than in both grains of corn and wheat (Table 4). The concentration of crude fat, calcium, and phosphorous are equal to the grain of wheat; besides, all these concentrations are larger than corn. In general protein and lysine in triticale are greater than wheat and rye protein. Metabolizable energy in hogs and poultry recorded 3200 kcal/kg, and this food energy is lower than others, while it is the same percentage in these three crops, as is clear in this table. Also, total digestible nutrients for ruminants (%) are approximately equal in triticale, maize, and wheat.

Table 4. *Comparative Constitution of triticale, maize, and wheat grain*

Item	Triticale	Maize	Wheat
Crude protein (%)	12.00	8.50	11.50
Lysin (%)	0.40	0.24	0.34
Crude fibre (%)	2.8	2.2	2.4
Acid detergent fibre (%)	3.8	2.8	3.5
Neutral detergent fibre (%)	12.7	9.6	11.00
Crude fat (%)	1.80	3.80	1.80
Calcium (%)	0.05	0.02	0.05
Phosphorous (%)	0.33	0.25	0.33
Metabolize energy in pigs (kcal/kg)	3,200	3,350	3,350
Metabolize energy in beef cattle (kcal/kg)	3,180	3,180	3,180
Metabolize energy in poultry (kcal/kg)	3,200	3,400	3,210
Total digestible nutrients for ruminants (%)	79.00	80.00	79.00

2.1.6. Yield

The grain yield of triticale differs between areas, soil types, cultivars and growing season. Grain yield varies between 1 t/ha in lower rainfall areas and areas with soil fertility problems, while it reaches more than 7 t/ha in higher rainfall areas with good fertile soil. In general, the average grain yield of triticale is close to 2.5 t/ha (Mergoum & Macpherson, 2004). Triticale could be cultivated on different soil types and responds well to the nitrogen level in the soil. In other words, it is suitable for areas where high manure and nitrogen fertilizers are applied regularly (Banaszak & Marciniak; Green, 2002). Regarding the Middle Eastern countries, triticale yield reached 2.15 t/ha in Iraq (Ali *et al*., 2021), while hay yield varied among countries. For instance, in Turkey it is between 12.77 t/ha to 18.68 t/ha. To get a higher yield than wheat, Bassu *et al*. (2011) recommended that farmers should consider planting an early vigor variety with more extended spike-formation phase along with improved remobilization of carbohydrates to the grain and more elevated transpiration use efficiency. Whish (2013) recommended the Australian farmers to consider the following tips before planting triticale to reach the maximize yield:

1. Studying triticale water requirement

2- Analyzing soil water ratio

3- Thinking about any risk may the farmers will suffer from it

4- Considering the fitting of this crop in the farms. Besides, considering the longer-term benefits to the system will outweigh any short-term losses or will not.

2.1.7. Cost and economical value

Calculating the cost and profitability of triticale depends on its uses and the cost and income from planting triticale. Kadakoglu *et al.* (2021) analyzed triticale production in 53 farms in Turkey in 2019, he concluded that triticale is highly profitable crop. Also in Ethiopia, Chanie (2014) found that triticale is more profitable than wheat and barley. That might be due to tolerance of triticale to various abiotic harsh conditions such as cold and droughts.

Regarding producing bioethanol fuel from triticale, many studies have proved that triticale is feasible economically. For instance, Denčić *et al.* (2012); (Salmon *et al.*, 2004) compared the cost of triticale with maize and wheat for producing bioethanol per production unit. The result showed that triticale was the lowest than maize and wheat in terms of cost. The total cost of producing 5.6 t/ha of grain yield of triticale was 499.0 €/ha, while the cost of producing 5.36 t/ha of grain yield of wheat and 7.92 t/ha of grain yield of maize was 535.67 €/ha and 674.36 €/ha, respectively.

2.1.8 Triticale growth and development

The primary advantages of triticale over cereal crops are (1) the ability to perform well on marginal lands, (2) a drought tolerant, (3) higher yield than wheat, (4) has superior digestible energy and crude protein levels and highly resistant to rust and smut.

2.1.9 Weather conditions

Triticale is winter hardy and tolerant of drought and widely adapted to various weather conditions. Many experiments were done in different regions to specify the best weather conditions for its growth. It was found that triticale grows well under rainfed conditions throughout different places in the world (Salmon *et al*., 2004). For instance, Derejko *et al*. (2021) examined triticale growth under different regions in Poland and under different growing seasons, they found that triticale is adapted to the temperate environment, and its yield is more steady and less dependent on the weather conditions than that of winter wheat (Table 5). The grain yield of winter wheat was between 9.22 and 15.72 t/ha while it was between 9.24 and 14.82 t/ha for triticale.

Table 5. *Average grain yield for winter wheat and triticale in six regions of Poland*

Species	Region	2011	2012	2013	2014
		t/ha			
Wheat	1	13.52	*10.40*	**13.90**	**15.72**
	2	13.45	**13.24**	12.53	14.44
	3	*11.35*	10.76	13.39	14.70
	4	12.10	10.57	11.59	13.42
	5	**13.61**	11.48	10.97	14.65
	6	12.47	11.53	9.22	*12.52*
Triticale	1	*10.93*	11.42	**12.33**	12.88
	2	**12.98**	**12.00**	11.79	**14.48**
	3	10.07	9.08	11.33	*11.80*
	4	10.87	10.18	9.81	11.90
	5	12.06	12.10	9.87	12.95
	6	11.07	11.41	*9.24*	12.71

Note. Italic type = minimum yield; bold type = maximum yield.

2.1.10. Soil conditions

Triticale grown well in all soils including light soil, marginal lands, waterlogged soils and those of high pH. Many researchers found that triticale is very responsive to phosphorus and nitrogen. Modern triticale cultivars have good aluminum tolerance, which becomes increasingly available in acidic soils, and have good efficiency for accessing major nutrients (e.g., phosphorus) and trace elements (manganese, copper, zinc) in alkaline soils, which have a rare ratio of them (Pena, 2004). Besides, under marginal land conditions, where abiotic stresses associated with soil conditions (extreme pH levels, salinity, toxicity, or deficiency of elements) are the limiting factors for grain production, modern triticale cultivars have always shown their advantages and have exceeded other crops (Mergoum *et al*., 1992). Richards *et al.* (1987) concluded that barely and triticale were more tolerant than wheat to drought in marginal lands and light soil. Akgün *et al*. (2011) found that triticale could be grown in high saline soil with an EC of 25 dsm^{-1}.

Triticale found to be tolerant to low soil pH and soils high in boron and aluminum (Chanie, 2014). Soil with high aluminum (Al) ratio critically limits growth of various crops in over 1.6 billion hectares globally. Kim *et al.* (2002) found that advanced triticale lines (AABBRR) revealed the highest degree of aluminum tolerance of all the triticale types and exceeded the observed levels in the rye.

2.1.11. Triticale cultivation

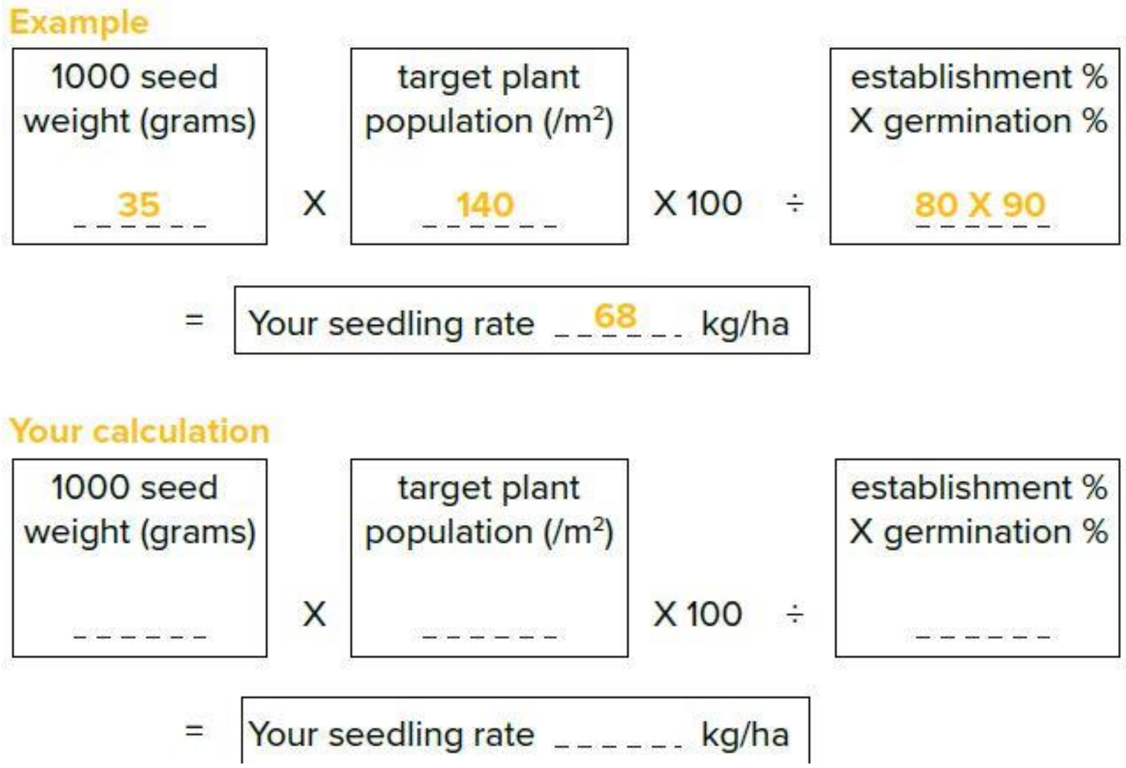
The cultivation of triticale varies between developed and developing countries and depends partly upon the availability of technology and cost. Other factors include the type of the soil and the amount of rain precipitation. Annual rainfall of 250 mm is considered the minimum. Triticale can be grown in soil less fertile than that required for wheat.

2.1.12. Seed preparation and rate

Various types of plowing tools could be used to render the soil more suitable for planting. Selection of equipment is mediated by various factors among them is the climate, the nature of the soil, and the rainfall. In general seedbed preparation for winter triticale parallel those of winter wheat and fall rye. Field operations should be completed by late summer.

Regarding seed rate, the desired density for triticale is 180 plants per m^2 or more depending on the seed size this equates to a seeding rate of 75 to 100 kg per hectare. Higher plant density should be adopted if sowing is delayed or when sowing on light sandy soils. Calculating sowing rate of triticale depends on the target plant density, germination percentage, seed size and establishment, as shown in Figure 4 (Matthews *et al.*, 2021).

Figure 4. *Measuring seed rate/area*



2.1.13 Sowing preparation

<u>2.1.13.1 Sowing date</u>

Sowing time has a great effect on the quality of triticale and differs between areas or regions, in general triticale is planted between September to October. Schwarte *et al*. (2005) identified sowing dates for winter triticale that would maximize nitrogen capture and dry matter yield in Iowa, USA. He found that delayed planting increased the production of dry matter. While early planting (September), triticale accumulated more nitrogen than October-planted triticale. Sowing time has also been examined in the central Appalachian Highland, USA (Clapham & Fedders, 2008). September-sown triticale yielded the highest dry matter than the October-sown triticale. Thus, it was concluded that year of sowing, month of sowing, month of harvest and interactions has a significant effect on dry matter yield. Ahmed and Ali (2015) reported that crop physiology and phenology rely on the sowing date in the rainfed areas. Therefore, the sowing date affects the biological parameters and grain yield. El-Metwally *et al.* (2012) found that the delayed sowing decreased grain yield by around 30%. Takahashi and Nakaseko (1993) indicated that sowing dates impacted alterations in assimilates availability during different phenological phases of the crop. Subsequently, that impacted the yield. As mentioned above, it has been clear that there are various sowing dates among countries. However, triticale seedlings must be subjected to vernalization, and thus early seeding is recommended.

2.1.13.2. Sowing depth

The depth of triticale seeds is more profound than other small cereals due to their massive size. Triticale cultivars are different in seed placement during the sowing process. In Australia, if triticale cultivars are planted at a depth of no more than 2.45 cm, the crop will be seen with uniform seedling emergence and early weed competition (Mergoum & Macpherson, 2004).

2.1.14. Triticale pests

2.1.14.1. Pathogens

The occurrence and spread of plant pathogens response to the development of new crop species and their related agro-ecosystems. The relatively recent introduction of triticale in cropping systems raised growing area, along with the general use of genetically uniform varieties, supplies a perfect case study for disease occurrence and spread. Since triticale's commercialization in the late 1970s, triticale has improved to be resistant to most cereal diseases. Unfortunately, this situation has changed in the last period, as several fungal pathogens have adapted to this recently introduced host (Oettler & Schmid, 2000; Pojmaj & Pojmaj, 1998; Schinkel, 2002). Overall, Audenaert *et al*. (2014) introduced that the vast majority of diseases that affect triticale are: Powdery mildew, leaf and stem rust and Fusarium head blight.

2.1.14.2. Insect

Studies showed that triticale varieties are attacked by a few insect pests (Mergoum & Macpherson, 2004). Most insects that affect triticale are grasshoppers, aphids, armyworms and cutworms. Controlling these insects are the same as for other cereal crops.

2.1.14.3. Weeds

Weed management in triticale is similar to that for cereal grains. Good soil fertility combined with planting certified seeds and vigorous germination/emergence is perhaps one of the most effective methods against weeds. Early planting and quick establishment will help triticale to stand and stave off early weed pressure. Most common weeds in cereals crops in Lebanon are: *Anthemis hyaline, Avena* spp.*, Capsella bursa-pastoris, Diplotaxis spp*, *Lamium amplexicaule*, *Lolium spp*, *Sinapis arvensis and Veronica polita*.

2.2. Plant nutrition requirement & nitrogen fertilization

2.2.1. Nutrition requirements overview

Triticale has similar nutritional requirements to wheat and responds well to most fertilizers. Generally, phosphorous and nitrogen are the most influential elements that affect triticale growth and yield. Triticale has similar phosphorus and nitrogen requirements as wheat. Many scientists indicated that triticale respond better to the most applied compound fertilizers than other crops in low nutrient soils. Triticale can utilize trace elements in soils that are considered low for any crop. Also, triticale has an extensive root system and can excavation the soil more efficiently than other cereals. Besides, to get a high yield and significant size grain biomass than wheat, farmers should increase the rate of nitrogen and phosphorus (Tshewang *et al.,* 2011). A good yield triticale requires phosphorous and nitrogen at sowing and more nitrogen application during the growing season.

2.2.2. Nitrogen overview

Nitrogen has been considered the most needed for triticale growth (Ladoni *et al.*, 2015).

2.2.2.1. Nitrogen use efficiency

Nitrogen use efficiency (NUE) is the efficiency of the soil nitrate when it is changed into grain nitrogen ratio. Many factors decrease this efficiency, like seasonal conditions, crop diseases, and nitrogen losses from the soil as gases, nitrogen leaching, or immobilization of nitrogen into organic forms. The sources of nitrate in soil are organic and inorganic fertilizers, crop residuals, manure, and organic matter. Optimizing nitrogen use efficiency needs to understand the importance of stable nitrogen in the soil organic matter, farmers should be careful about how much of each source there is, and of course, soil testing before planting to know these nitrogen sources. Thus, nitrogen rates are adjusted according to the size of the crop canopy (Schwenke *et al*., 2013).

2.2.2.2. Nitrogen stress

Nitrogen deficiency stress occurs when the nitrogen level in the soil falls below the sub-millimolar range. Hence, that leads to nitrogen starvation. However, the precise threshold varies based on the plant, duration of exposure, soil type, organic matter content, microbial activity, cropping methods, and environmental conditions (Jangam & Raghuram, 2015). Nitrogen stress is caused by extreme fluctuations in the soil nitrogen level or due to the formation of nitroso compounds in the plant as a consequence of other stresses" (Jangam & Raghuram, 2015). The nitrifying bacteria break down organic nitrogen sources (manures/urea), converting them into inorganic compounds such as nitrates and ammonium salts. The response of plants to nitrogen availability depend on both genotype and the interaction of genotype with nitrogen supply level (Chardon *et al*., 2010; Gallais & Hirel, 2004). For instance, plants respond to nitrogen starvation or deficiency by changes like an increase in the root to shoot ratio or by supporting lateral root growth or inhibiting shoot growth or early senescence of leaves (Marschner, 1995).

2.2.2.3. Nitrogen fertilizers overview

The most common nitrogenous fertilizers are synthetic ammonia, nitric acid, ammonium nitrate and urea. The purpose of producing synthetic ammonia and nitric acid is to use them as intermediates in ammonium nitrate and urea fertilizers. The following list shows the most common nitrogenous fertilizers, while Table 6 gives information about the product characterization summary of nitrogenous fertilizers.

- Ammonia liquor
- Ammonium sulfate
- Anhydrous ammonia
- Aqua ammonia

- Fertilizers, mixed, produced in nitrogenous fertilizer plants
- Fertilizers, natural
- Nitric acid
- Nitrogen fertilizer solutions
- Plant foods, mixed in nitrogenous fertilizer plants
- Urea.

Table 6. *Most common nitrogen fertilizer products*

Nitrogenous Fertilizer Products	Profile
Synthetic ammonia (NH_3)	It has been made from natural gas. In other words, natural gas molecules are changed to carbon and hydrogen. Therefore, the hydrogen is purified and reacted with nitrogen to make ammonia. The USA used approximately 75% of the synthetic ammonia as a fertilizer, either directly as ammonia or indirectly after ammonia synthesis into urea, ammonium nitrate, and mono ammonium or diammonium phosphates. The fertilizer nitrogen ratio was applied directly to the land as anhydrous ammonia close to 35%.
Nitric Acid (HNO_3)	It is made by concentration, absorption, and oxidation of anhydrous ammonia. Approximately seven-tenth of the nitric acid produced is utilized as an intermediate in making ammonium nitrate (NH4NO3), primarily used in fertilizers.
Ammonium nitrate (NH_4NO_3)	It results from a chemical combination of nitric acid with ammonia. About 15–20% of ammonium nitrate is utilized for explosives and the balance for fertilizer. Many ammoniums nitrate forms in the markets; it depends on its use. Liquid ammonium nitrate is perhaps marketed as a fertilizer because it commonly combines with urea. The general form shapes of

	Solid ammonium nitrate as prills because low-density could be utilized as fertilizer making and explosive manufacturing.
Urea (CH_4N_2O)	It is additionally known as carbamide or carbonyl diamide, produced by the neutralization of ammonia with carbon dioxide. 85% of urea solution manufactured is utilized in fertilizer combinations. The most solid urea forms are consumed as fertilizer or protein supplement in animal feed and plastics production.
Ammonium sulfate $(NH_4)_2SO_4$	It is not economically feasible to manufacture ammonium sulfate for use as a fertilizer.
NPK	It consists of a mixture of ammonium sulfate $(NH_4)_2SO_4$, superphosphate $CaH_4P_2O_8$, and muriate of potash KCl, which provide N, P, and K, respectively. The NPK fertilizers have many forms, such as an NPK compound 13-13-21, which means that the percentage of N: P2O5: K2O in the compound is 13% N, 13% P2O5, and 21% K2O. Furtherly, NPK combinations are 10-15-20, 15-15-15, 12-12-17, 12-12-20. Combinations of N and P, N and K, and N and K are also made and available in the markets. NPK fertilizer has been regarded as complex fertilizer granules, which has many positive traits like being free-flowing, resistant to physical damage and moisture, and easy to handle.

Adapted Source: (Cheremisinoff & E. Rosenfeld, 2011; Scherer, 2005)

2.2.3. Nitrogen fertilizer application

According to various studies, it was found that nitrogen application is crucial for the growth and development of triticale in particular to the grain yield and dry matter under drought conditions (Figure 5). The time of application of nitrogen fertilizer depends on three factors: growth stage, targeted grain yield and the targeted ratio of grain protein, as shown in Table 7. For instance, if the targeted grain yield is 4 t/ha at 12%, the sufficient nitrogen fertilizer will be 112 kg/ha at the maturity stage and 90 kg/ha at the anthesis stage. However, splitting and delaying applications could be helpful strategies to manage growth yield and grain protein concentration under irrigated system. However, it not advisable to use this strategy under low rainfall conditions (i.e., when average target yields are 1.5 t/ha or less). Therefore, adding the first application of nitrogen fertilizer should be at planting and the second application during the growing season to satisfy the nitrogen requirement for plants (McDonald & Hooper, 2013).

Figure 5. *Triticale grain yield and straw dry-matter response to nitrogen levels under drought conditions in Morocco*

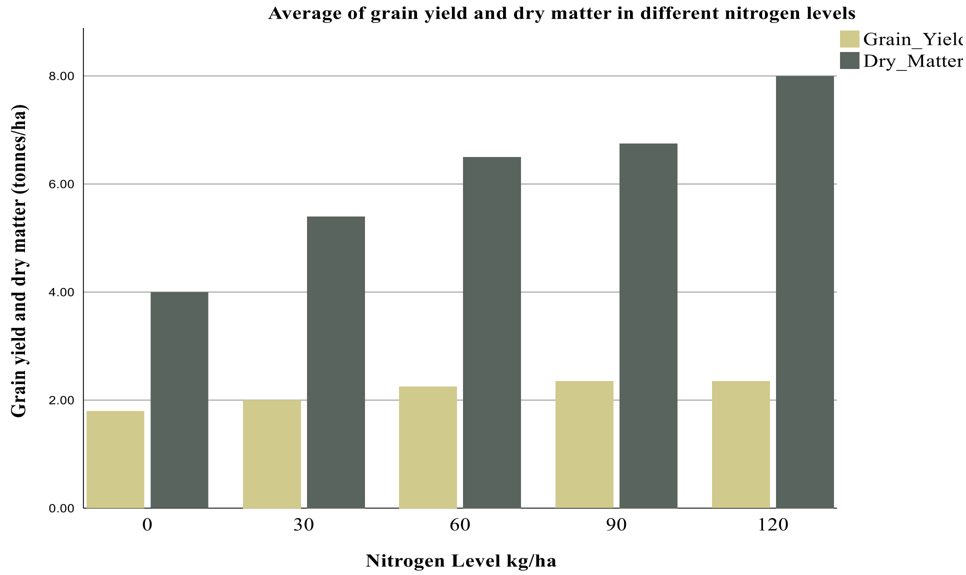


Table 7. *Nitrogen requirements for cereal crops at different combinations of yield and grain protein at maturity, and the corresponding N required at anthesis*

Grain Yield (t /ha)	Growth Stage	Grain Protein (%)				
		9	10	11	12	13
		Kg N/ha				
1	Maturity	21	23	26	28	30
	Anthesis	17	19	21	22	24
2	Maturity	42	47	51	56	61
	Anthesis	34	37	41	45	49
3	Maturity	63	70	77	84	91
	Anthesis	51	56	62	67	73
4	Maturity	84	94	103	112	122
	Anthesis	67	75	82	90	97
5	Maturity	105	117	129	140	152
	Anthesis	84	94	103	112	122
6	Maturity	126	140	145	168	182
	Anthesis	101	112	124	135	146

2.2.4. Impact of nitrogen deficiency on triticale

The role of nitrogen is essential for the growth of plants. The shortage of nitrogen affects the weight and number of shoots. Besides, it also represents the photosynthesis process because the ratio of chlorophyll differs in different ratios of nitrogen in the soil. Grzesiak *et al.* (2018) experimented two varieties of triticale (CHD -12 and CHD-247) to various nitrogen levels. They concluded that the root growth of triticale significantly increased with increasing the soil's nitrogen content. In soil low in nitrogen, triticale become underdeveloped and leaves were yellow. The color of triticale leaves changed from yellow to brown-necrosis when triticale suffered from a shortage of nitrogen. Another mark of nitrogen deficiency appeared in the variance of the total root length and total root number between these different nitrogen levels (Table 8).

Table 8. *Influence of different soil nitrogen content for two triticale breeding form for many traits*

	Triticale breeding form (CHD-12)			Triticale breeding form (CHD-247)		
Traits	Poor in nitrogen content	Control	High in nitrogen content	Poor in nitrogen content	Control	High in nitrogen content
Shoot weight (g/plant)	3.53	3.37	4.22	2.88	3.04	3.88
Roots weight (g/plant)	1.93	1.88	2.31	1.72	1.79	2.43
Shoots/Roots (rel. units)	1.8	1.8	1.8	1.6	1.7	1.6
Chlorophyll Content (rel. units)	7.52	9.65	12.32	6.96	8.55	10.19
Total root number (no plants^{-1})	69.6	56.5	84.0	78.0	49.2	83.7
Total root length (cm plants^{-1})	102.9	81.1	123.3	116.5	73.3	124.3

Source: Adapted from (Grzesiak *et al*., 2018)

2.2.5. Impact of nitrogen excess on triticale

Nitrogen fertilization found to improve the yield and protein content of various crops. However, applying excessive amounts of nitrogen fertilization under certain conditions such as drought, frost, temperature, herbicide, etc. enhanced the accumulation of nitrate (NO_3^-) in plants and lead to their death (Fresneau *et al*., 2007; Nešić *et al.*, 2008; Zhang *et al*., 1999). High nitrogen concentration is not common in well-managed soil because of microbial decomposition, surface runoff, and volatilization, or leaching. Wang *et al*. (2008) found that application of urea at 100 kg/ha of urea fertilizer did not affect triticale growth. This rate had been regarded as over-fertilizing, but the symptoms of excessive nitrogen did not appear. In general, urea-degrading enzymes by microorganisms break down urea quickly in the soil (Watson *et al.*, 1994). Therefore, urea concentrations in natural environments (i.e. lakes or agricultural soils) are low, so urea concentrations often are <70 μM in agricultural soils (Becker-Ritt *et al.*, 2007).

Gulmezoglu *et al*. (2010) experimented with the impact of different rates of nitrate on triticale. The experiment was conducted under dryland field conditions for two years by applying control, low and high nitrogen fertilization rates (0, 40, 80 and 160 kg/ha). The results showed a positive relationship between the nitrate content of forage and the high nitrogen application rates in both two years. The results of this experiment appeared that the accumulated nitrate amount in the triticale cultivars was different based on the growing year, the stages of the forage sampling, and the application rates on nitrogen fertilization.

2.3. Water requirement

Triticale has been considered a perfect crop to be grown under drought conditions and water stress. A 24-year study was conducted for wheat and barley and a 15-year study for triticale in Poland found that these crops cereals needed between 293 and 314 mm of soil water during the growing season (Martyniak, 2008). Triticale gave the highest grain yield compared to all these cereals. The average grain yield of triticale reached 1.65 t/ha, whereas the average grain yield of wheat and barley reached 0.87 t/ha and 0.73 t/ha, respectively (Table 9). It seems that triticale has some drought tolerance because it has early vigor stemming from its rye heritage. In Australia, triticale is better than wheat and barley regarding the adaptability of drought stress (Jessop, 1996).

Table 9. *Comparison of grain yield between barely, wheat, and triticale*

Species	Mean of Grain Yield (t/ha)
Barely	5.07
Wheat	5.16
Triticale	5.30

2.3.1. Soil moisture

It is well documented that soil moisture affects seed germination and seedling emergence of various crops (White & Edwards, 2008). In general, triticale needs an annual average rainfall between 300-900 mm per season under rainfed conditions. Thus, supplemental irrigation in arid conditions is required (Cooper *et al*., 2004).

2.3.2. Cultivating triticale under rainfed conditions

Rainfed agriculture covers 80% of the world's cultivated land and contributes about 60% to the total crop production. Low crop productivity in various arid and semiarid rainfed agricultural systems is often due to degraded soil fertility, low rainfall, high evaporation and limited nutrients input (UNESCO, 2009). In Lebanon, rainfed cereals accounts for over 60% of the arable land and about 40% of Lebanon's population depends on rainfed agriculture. With rising concerns over water availability and the high cost of irrigation, rainfed agriculture is gaining increased attention. Thus, there are various options for increasing "crop yield per drop," such as introducing triticale to Lebanon.

Triticale is mainly grown under rainfed conditions all over the world. Schillinger and Archer (2020) compared winter triticale with winter wheat in the dry Mediterranean climate in the United States of America for nine years. The minimum precipitation level was 256mm in 2014, and the maximum precipitation level was 440mm in 2017. Over the nine years, the researchers could produce 14% and 24% more grain yield of winter triticale than winter wheat, respectively. The range of winter triticale grain yield was from 4.4 to 7.4 t/ha with an average of 5.8 t/ha, whereas the average grain yield of winter wheat was 5.1 t/ha.

Planting triticale thrived well under rainfed conditions throughout the world and excels when produced with good soil fertility and irrigation (Mergoum & Macpherson, 2004). It is cultivated in areas with an annual average rainfall of between 300 mm and 900 mm (Cooper *et al*., 2004). Lopez-Castaneda and Richards (1994) compared planting triticale with barley, wheat and oat to know the highest grain yield and total biomass of these crops under rainfed conditions. The results showed that barley and triticale achieved a greater leaf area and dry mass faster than the wheat and oat. However, barley grain yield and total biomass were higher than triticale, which in turn yields more biomass than bread wheat, durum wheat and oats.

Regarding the analysis of triticale seed planted under rainfed conditions, Sirat *et al*. (2022) reported that the average contents of triticale seeds collected from plants growing for 2 years under rainfed conditions were, protein 10.56-12.09%, starch 64.74-68.19%, moisture 9.44-9.72%, ash 1.25-1.60%, oil 0.79-1.27%, ADF (acid detergent fiber) 3.22-4.39%, NDF (neutral detergent fiber) 15.14-16.88%, potassium 0.432-0.527%, magnesium 0.113-0.135%, and phosphorus 0.360-0.387%. On the other hand, Maresma *et al.* (2021) compared eight winter species (barley, Italian ryegrass, oats, oats plus vetch, triticale and wheat) grown under irrigated Mediterranean conditions. Results showed that triticale recorded the highest yields, but the forage quality parameters showed low protein content and digestibility and high acid detergent fiber and neutral detergent fiber values compared with the other varieties.

2.3.3. Cultivating triticale under supplemental irrigation system conditions

Drought stress in triticale is generally better than other crops. Ekiz *et al.* (1998) found that irrigation could increase both shoot zinc content of different cereal cultivars. Another study was conducted in Iran by Barati *et al.*, (2020) to specify the best nitrogen application and watering system regimes associated with planting triticale. The nitrogen application included Azospirillum brasilense (Biofertilizer), Azospirillum brasilense+75 kg N/ha, 150 kg N/ha, and control. The watering system regime included normal irrigation, irrigation cut off after the anthesis stage, and rainfed treatment in the second year. Results showed that the highest grain yield (6.25 t/ha) was obtained by nitrogen fertilizer at 150 kg/ha under normal irrigation. While Bio+N75 gave the highest grain yield compared with other nitrogen sources under irrigation (4.4 t/ha) and rainfed conditions (2.96 t/ha) (Barati *et al*., 2020).

Regarding the times and dates of supplemental irrigations that should be done, Sarkar and Paul (2000) suggested that if there is just single irrigation that farmers can do, it should be applied at the boot stage of the wheat crop. Moreover, if the farmers could apply second irrigation, it should be applied at the crown root initiation of the same crop. If three irrigations can be applied, the water should be applied at 50% booting, 50% flowering, and 50% grain formation stages. Thakur *et al*. (2000) reported that if wheat received four irrigations at crown root initiation, maximum tillering, boot, and milk stages led to maximum grain and straw yields of wheat.

2.4. Grain content

The nutritional value of forage crops accounted for two-thirds or more of the cost of livestock production, and the quality of these crops is a key to increasing performance and decreasing the environmental impact of livestock production (Millet *et al*., 2018). Analysis of the nutrient ingredient of forage crops, which comprises analysis of protein, fat, and fiber, and benefitting from this information to correct for variances in composition lead to taking an overview of the nutritional value of these crops (Henry *et al*., 1988; Just *et al*., 1984; Noblet & Perez, 1993). In our experiment, the analysis of grain content of triticale was done by using NIRS (near-infrared spectroscopy) machine to study the impact of different nitrogen fertilizer applications and watering systems on the grain content. Therefore, this part shows three points, which are:

2.4.1. Comparison between NIRS technique and wet chemistry for analyzing grain content of agricultural products

Norris (1996) reported that near-infrared spectroscopy (NIRS) was widely employed to estimate the nutritive quality of agricultural products for many decades. For this reason, NIRS can indicate the physical and chemical properties of the forage crops, like the content of crude protein (CP), amino acids, acid detergent fiber (ADF), neutral detergent fiber (NDF), and starch (Barton 1991; Campo *et al*., 2013; Williams & Cordeiro, 1979). Wet chemistry has been utilized to analyze forage crop value. However, researchers and many analytical laboratories have changed their methods from wet chemistry analysis methods to near-infrared spectroscopy (NIRS) to estimate forage crop value because wet chemistry takes a long time combined with that is expensive and unsafe sometimes. The second reason for changing the analysis of nutritive feed value by relying on wet chemistry to the NIRS technique is that NIRS showed good consistency for all the measurement parameters compared to wet chemistry. As a result, there is a strong correlation and similarity between the analysis results of the nutritional value of forage crops, whether using traditional wet chemistry or the NIRS technique (Harris *et al.*, 2018;

Safiqur *et al*., 2021). Harris *et al*. (2018) explained which chemistry method was used to analyze feed nutritive value relying on wet chemistry and analyzed nutritional components (Table 10). Moreover, the researchers showed the analysis results of both wet chemistry and NIRS, as provided in Table 11. The results of both methods had clear consistency and strong correlation.

Table 10. *Details of the analysis and methods used*

Nutritive components	NIRS	Wet chemistry
Crude protein	Own method	Kjeldahl destruction, NEN-ISO 5983-2
Crude fat	Own method	Extraction using petroleum ether gravimetric detection of the fat faction. NEN-ISO 6492
Crude fiber	Own method	Extraction using diluted sulfuric acid and sodium hydroxide—gravimetric detection of the organic matter. NEN-EN-ISO 6865
Neutral detergent fiber	Own method	Extraction using an ND solution and amylase—gravimetric detection of the organic matter. NEN-EN-ISO 16472:2006
Sugar	Own method	Luff-Schoorl. Extraction using water/ethanol (40/60) photometric detection using neocuprin color reagent. EC Regulation 152/2009; NEN-EN-ISO 6498:2012

Table 11. *Mean results of nutritive components (g/kg) by using NIRS technique and wet chemistry methods*

Nutritive components	NIRS mean results	Wet chemistry results
Crude protein	71.2	68.8
Crude fat	18.8	16.6
Crude fiber	324	329
Neutral detergent fiber	619	627
Sugar	106	102

2.4.2. Impact of fertilization program on the grain content of triticale

Many studies showed that fertilizers had a significant effect on the grain contents of cereals. Moinuddin and Afridi (1997) experimented nine nitrogen and phosphorous rates on grain protein of four cultivars of triticale, wheat and rye. Results showed that the protein content increased with increasing the composition of fertilizers up to 200N+ 40P kg/ha, as is presented in Table 12.

Table 12. *Different protein ratios under different combined N+P levels for different crops cultivars*

Cultivar	Combined N+P fertilizer levels (kg/ha)								
	180	190	200	230	240	250	280	290	300
Triticale1	9.8	11.1	10.8	11.6	12.8	12.6	12.3	13.4	11.4
Triticale2	10.9	11.6	12.1	12.4	13.3	12.7	12.7	13.0	12.8
Triticale3	7.9	8.9	9.6	11.3	12.8	12.8	12.8	12.0	11.8
Triticale4	12.1	13.7	13.9	15.1	16.7	15.9	16.0	15.4	15.7
Wheat	10.7	11.6	12.1	12.7	13.8	13.0	12.6	12.8	12.6
Rye	10.7	12.3	12.5	13.1	13.9	13.0	12.4	12.8	12.7

Source: Adapted from (Moinuddin & Afridi, 1997)

2.4.3. Impact of Watering systems on the grain content of triticale

Water deficit is the most influential factor affecting crop growth and development. Since water resources in arid and semi-arid areas are very scarce, many experiments were conducted to study the impact of water on the grain content of triticale. For instance, Saed-Moucheshi *et al.* (2019) estimated the protein content of wheat under normal irrigation and drought stress conditions in Iran. They found that under normal irrigation, the protein ratio was 15.1, 12.8, and 15.6, respectively, while under drought conditions, it was 35.4, 34.0, and 35.7 respectively. Fernandez *et al.* (2000) reported an inverse relationship regarding carbohydrates and protein accumulation under non-stress conditions. This may be due to the competition between nitrogen and carbohydrates for energy and carbon skeletons. It is similar to a delay in leaf-protein hydrolysis to keep the photosynthetic rate affected by the high demand of assimilates by growing grains. It was concluded that the protein ratio was higher under drought stress conditions. Silva *et al.* (2020) experimented with the response of protein and ash ratio of common bean, triticale, and wheat to water stress by applying different water regimes. The result showed that there was no significant difference between the ratios of protein and ash under different irrigation regimes.

2.5. Grain morphology

Grain morphology is of interest in crop improvement because of its relationship to yield and quality (Ferrari *et al.*, 2021). One of the main features of the domestication syndrome in crops is a boost in grain size (Brown *et al.*, 2009; Fuller, 2007). Therefore, for some crop species like rice, where the domestication procedures included strong selection both for grain size and shape (Kovach *et al.*, 2007). The marketing assessment has focused on grain shape since it has influenced crop milling performance (e.g., flour quality and yield), especially the crops were utilized for baking bread like wheat and others. Optimizing grain shape and size combined with large and spherical grains was the prediction of theoretical models for increasing milling yield (Evers *et al.*, 1990). Average grain weight per area unit is related to the change in grain size traits because these changes could lead to an increase in competition during grain filling (Cartelle *et al*., 2006; Labra *et al*., 2017; Sakai & Sakai, 2005) or a decrease in the grain size measurements (Elia *et al*., 2016; Slafer *et al*., 2015).

In general, there is a little research about the watering system's impact on grain morphological traits of triticale. Nassir and Alawode (2016) experimented with studying the impact of genotype, environment, and the interaction between genotype and environment on the grain size measurements of rice under rainfed conditions in two sites in Nigeria. This experiment was conducted under two tropical rainforest ecology from 2001 to 2004. As a result, there was variation in the quantity of rain precipitation. Grain morphological characters and hundred-grain weight recorded significant genotype, environment, and genotype-by-environment interaction.

Table 13 shows the mean squares of grain shape size (grain length and width) and hundred-grain weight of rice that responded to the impact of genotype, environment, and genotype × environment. The highest mean square of hundred-grain weight and grain width resulted from the impact of the environment, 3.78 and 4.81g, respectively, while the impact of genotype was accounted for the first ranking regarding the grain length, 0.75 mm, and the second ranking regarding hundred-grain weight and grain width, 2.40 g and 0.75 mm, respectively. It seems that the different quantities of rain precipitation during the period of conducting this experiment led to be the most influential factor.

Table 13. *Mean squares of hundred-grain weight and grain length and width of rice*

Source of Variation	Hundred grain weight (g)	Grain length (mm)	Grain width (mm)
Genotype	2.40 **	1.09**	0.75**
Environment	3.78**	0.88**	4.81**
Genotype × Environment	0.36**	0.72**	0.16**

** Significant at $P < 0.01$; Adapted source: (Nassir & Alawode, 2016)

CHAPTER 3

MATERIALS AND METHODS

Two adjacent field experiments were conducted at the Advancing Research Enabling Communities Center (AREC) of the American University of Beirut during the fall 2020 and spring 2021 seasons. The AREC is located in the Northern Beqaa plain with an altitude of around 1000 m above sea level at 34° 54''N latitude and 36° 45''E longitude. The aim of both field experiments was to study the effect of nitrogen fertilizers on the growth and development of triticale under rainfed and supplementary irrigation

3.1. Soil analysis

Soil samples were collected at 30cm depth from different places in the field during soil bed preparation. Sampling at 30 cm depth is considered a common method practiced by farmers in the cultivated fields of Lebanon (Bashour & Sayegh, 2007). Analysis was done for soil texture, soil pH and EC, available phosphorous, available potassium, $CaCO_3$ %, and the ratio of nitrogen-nitrate and total nitrogen. Analysis was done according to Bashshūr and al-Ṣāyigh (2007), except for calculating the ratio of nitrogen-nitrate and total nitrogen, which were done in Laboratories for the Environment, Agriculture, and Food (LEAF).

3.2. Sources of triticale seeds

The variety of standard triticale seeds used in this experiment was "*De Mantillo, Italy origin".* Both the seeds and fertilizers were obtained from local agents.

3.3. Types of chemical fertilizers

Two inorganic fertilizers were used in both experiments:

1. Granular nitrogen fertilizer 40-0-0, made in China.
2. NPK 15:15:15, made in Vietnam.

3.4. Experimental description

Both experiments (Rainfed and supplementary irrigation) were conducted beside each other on an area of 1250 m^2/each.

3.5. Experimental design

Experiments were conducted as a randomized complete block design (RCBD) with four replications/experiment (Figure 6). Blocks were separated by 2.5m aisles. Each experiment was divided into 28 plots per experiment. The area of each plot was 21m^2 (6m length × 3.5m width). Each plot consisted of 22 rows, 15 cm between rows and 10cm within the row. The total area of each experiment was 588m^2 (7 treatments × 4 replicates). Treatments and their plots or replicates are listed in Table 14.

Figure 6. *Field map description*

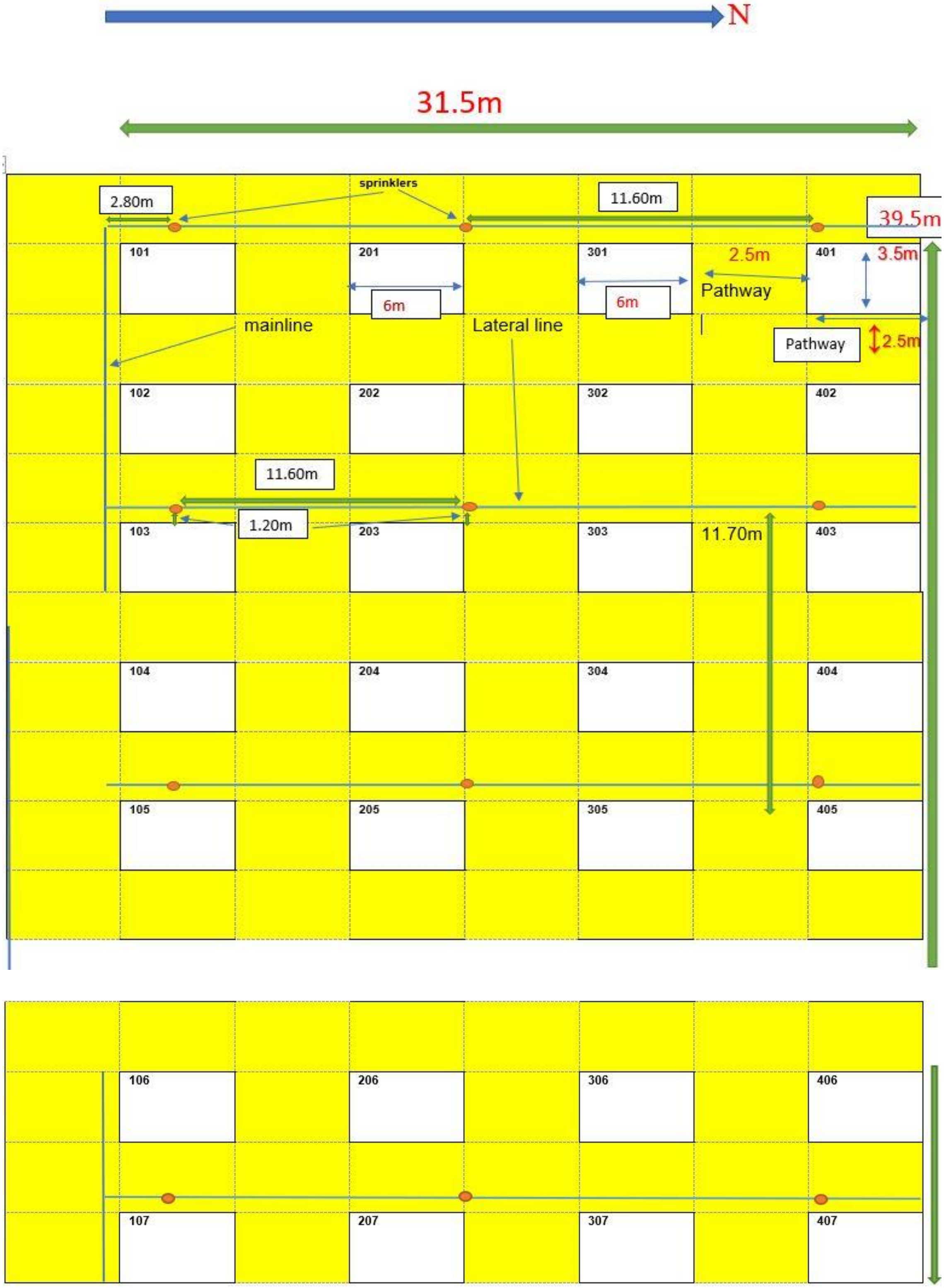


Table 14. *Treatments and their corresponding replicates*

Treatment	Rate Kg/ha	Rate Kg Pure N/ha	Rep1	Rep2	Rep3	Rep4
Control	0	0	101*	207	302	404
NPK	100	15	102	206	303	401
N	40	16	103	205	301	407
N	80	32	104	204	306	403
N	120	48	105	203	307	402
N	160	64	106	202	304	405
N	200	80	107	201	305	406

101*: 1 is block one and 01 is rep 1.

3.6. Land preparation

Seed bed of both fields were prepared with a squared moldboard plow followed by rotary tillage to break soil clods and to incorporate materials thoroughly into the soil. Both operations were done two weeks before sowing triticale seeds (Figure 7).

Figure 7. *Primary tillage with a moldboard plow*

3.7. Sowing triticale seeds

Thirty kilograms of triticale seeds were used for both experiments (19.4g/m^2). The average triticale population was 12 plants/m^2 in both experiments. Seeds were planted on November 20, 2020, by grain drill which includes 24 furrow openers spaced 15 cm (Figure 8). Cambridge Roller was used after the sowing as exhibited in Figure 9.

Figure 8. *Planting triticale with agricultural grain drill*

Figure 9. *Rolling the field after sowing with a Cambridge Roller*

3.8. Nitrogen fertilization treatments

For both experiments, treatments included different rates of nitrogen and one rate of NPK. The first application included a single application of the whole amount of NPK (15:15:15) and 30% of the whole applications of nitrogen fertilizer. Both were applied as band application. A single application of NPK was used according to the standard crop management strategy used by farmers in the Beqaa plain. The second application included 70% of nitrogen fertilizers applied 102 DAP. The rate and application time of fertilizers were made according to the results of soil chemical analysis and upon the recommendation of our soil expert, Dr. Bashour. Many scientists found that splitting and delaying applications of nitrogen fertilizers are excellent strategies to enhance growth yield and grain protein concentration of crop cereals. It was found that the time of application of nitrogen fertilizers depends on growth stage, targeted grain yield and the targeted ratio of grain protein (Table 15). For instance, if the targeted grain yield is 4 t/ha at 12%, the needed nitrogen fertilizer will be 112 kg nitrogen/ha at the maturity growth stage and 90 kg nitogen/ha at the anthesis growth stage (Table 16).

Table 15. *Nitrogen requirements for cereal crops at various combinations of yield and grain protein at maturity, and the corresponding nitrogen required at anthesis*

Grain Yield (t /ha)	Growth Stage	Grain Protein (%)				
		9	10	11	12	13
		Kg N/ha				
1	Maturity	21	23	26	28	30
	Anthesis	17	19	21	22	24
2	Maturity	42	47	51	56	61
	Anthesis	34	37	41	45	49
3	Maturity	63	70	77	84	91
	Anthesis	51	56	62	67	73
4	Maturity	84	94	103	112	122
	Anthesis	67	75	82	90	97
5	Maturity	105	117	129	140	152
	Anthesis	84	94	103	112	122
6	Maturity	126	140	145	168	182
	Anthesis	101	112	124	135	146

Table 16. *Fertilizers treatments and their rates*

Treatment	Rate Kg/ha	1st Application at planting Kg/ha (30%)	Total rate g/Plot	2nd Application after 100DAP Kg/ha (70%)	Total rate g/Plot
Control	0	0	0	0	0
NPK	100	100*	210	0	0
N	40	12	25.2	28	58.8
N	80	24	50.4	56	117.6
N	120	36	75.6	84	176.4
N	160	48	100.8	112	235.2
N	200	60	126	140	294

* NPK was applied as a single application at planting.

3.9. Irrigation system

Two irrigation systems were used in this study:

1. Zero irrigation (Rainfed conditions)
2. Supplemental irrigation.

3.9.1. Estimating soil moisture

Figure 10 shows the total precipitation of rain for 2020 and 2021. It has been clear that the total precipitation of rain in 2020 was more than 2021, 476 mm and 396.6 mm, respectively. Figure 11 shows the total precipitation of rain before crop planting date (between 1/9/2019 and 20/11/2020), and after crop planting date to the harvesting crop date (between 20/11/2020 and 5/7/2021).

Soil moisture was measured before and after each supplementary irrigation. Soil moisture by mass was calculated as shown below:

$$\text{Soil Moisture by Mass\%} = \frac{Water\ Weight}{Microwave\ Dry\ Weight} \times 100$$

Table 17 gives information about the soil moisture at two depths (30 cm and 50 cm) during the growing season. Besides, it gives information about irrigation days after planting date and amount of precipitation by supplemental irrigation. Table 18 describes the information associated with soil moisture at two depths and many parameters used to account for the soil moisture by mass.

Figure 10. *Accumulative precipitation of rain for two years*

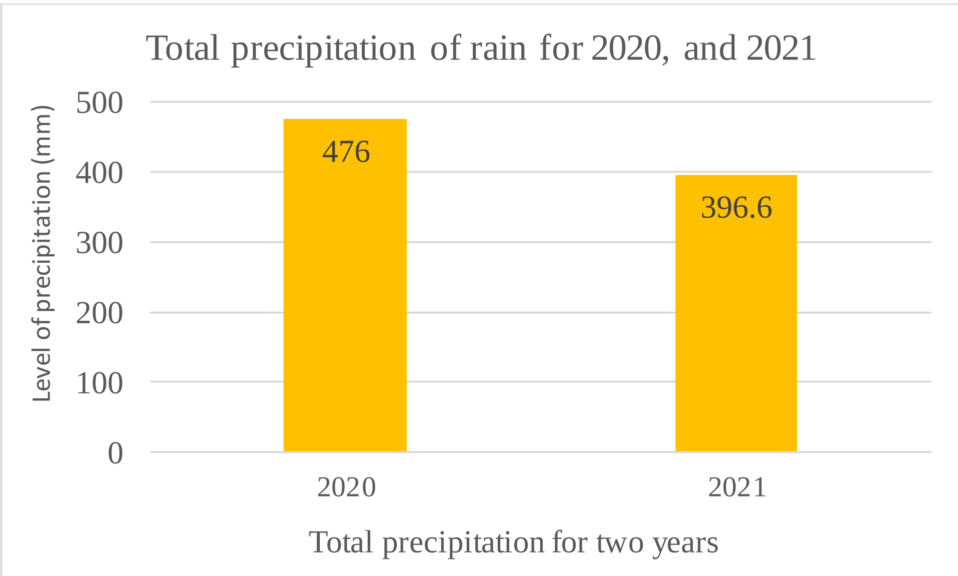


Figure 11. *Accumulative precipitation of rain before and after crop planting date*

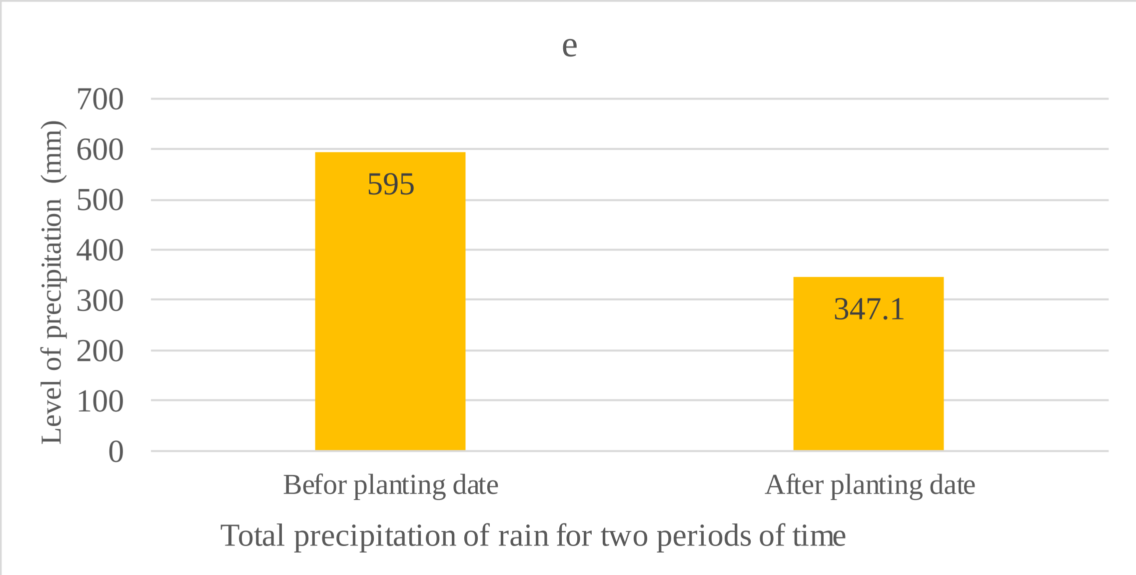


Table 17. *The ratios of the soil moisture by mass in different depths, and in different dates and irrigation dates after planting*

Days After Planting DAP	Soil Moisture % (30cm depth)	Soil Moisture % (50cm depth)	Irrigation Days After Planting	Precipitation mm
146	27.02	21.35		
148			148	51
153	28.90	25.27		
157			157	68
158	29.97	34.21		
159				
172			172	51
174	28.50	28.27		

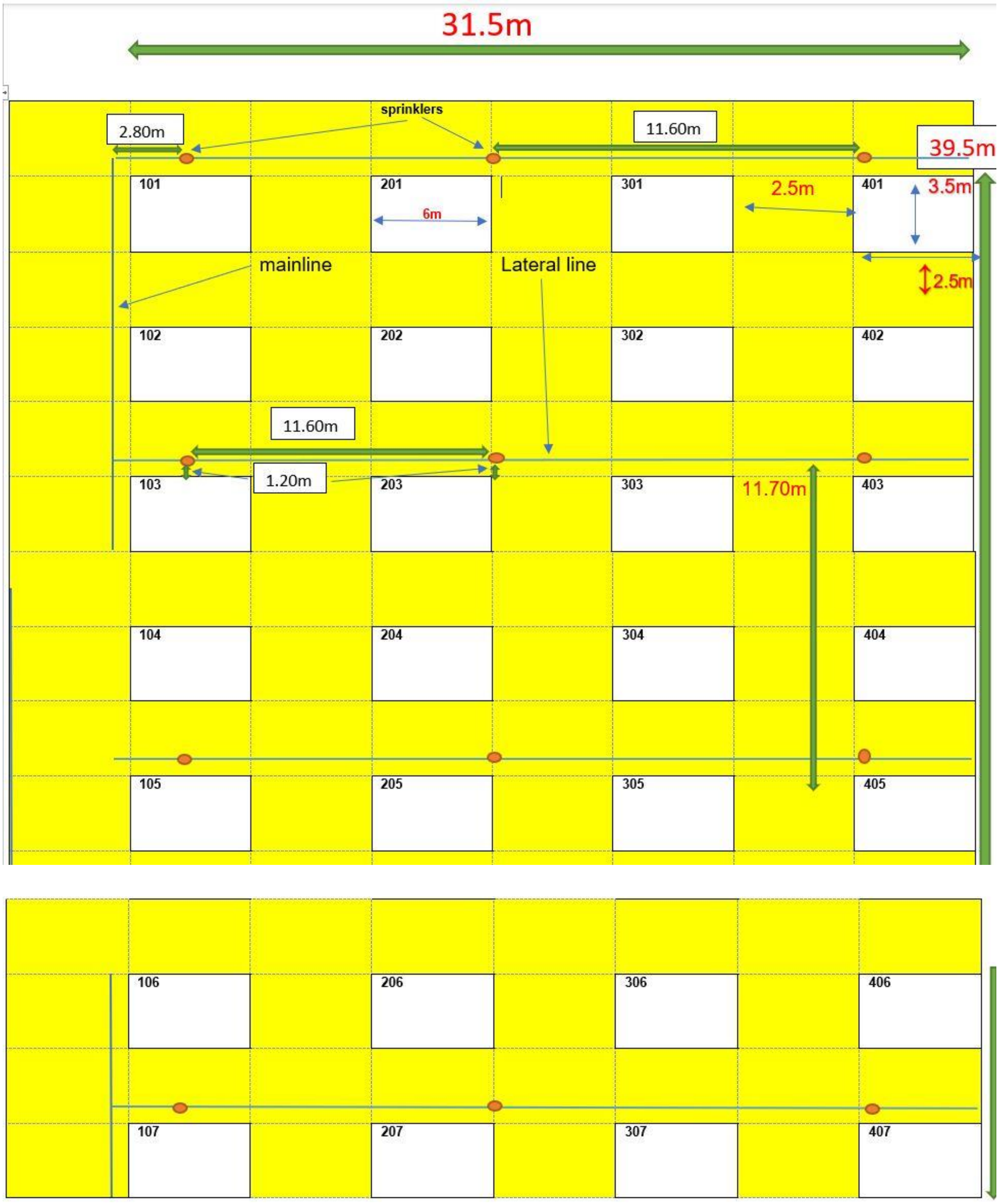
Table 18. *Information that was related soil moisture at depth 30cm and 50cm, precipitation, and other parameters resulting in accounting soil moisture by mass*

Date of collected sample soil after planting date	Depth (cm)	Soil sample weight (g)	Microwave dry weight (g)	Water weight (g)	Soil Moisture by mass (%)
146	10	50.10	38.60	11.50	29.97
146	30	50.30	39.60	10.70	27.02
146	50	46.60	38.40	8.20	21.35
153	30	57.00	44.50	12.50	28.90
153	50	57.00	45.50	11.50	25.27
158	30	50.3	38.7	11.6	29.97
158	50	51.0	38.0	13.0	34.21
174	30	51.4	40.0	11.4	28.50
174	50	49.9	38.90	11.0	28.27

3.9.2. Supplemental irrigation system

The supplemental irrigation system was a fixed sprinkler system with a maximum flow rate of 1.9 m^3/hr at a pressure of 3.8bar. At this pressure, each sprinkler precipitated 17mm of water/hr. The sprinkler type was Rain Bird 14070H ¾” (19mm) Full Circle, Brass Impact Sprinkler. Regarding lateral lines, they were four and the distance between them was 12m. Every line had three sprinklers with a total of twelve. Figure 12 shows the spatial arrangement of the sprinklers.

Figure 12. *Sprinkler, main line, and lateral line distribution chart*



3.10. Data collection

The collected data were crop density (the number of plants/m^2), plant height (3 times), fresh weight, dry weight of the whole triticale plant including shoots (twice), spike number per m^2, spike weight per m^2, grain weight per m^2, thousand-grain weight, hay dry weight per m^2, and seed analysis (n=1000 seeds). The average number of plants/m^2 was 293. Spike number per m^2 was measured by using a 1x1m metal frame. Figure 13 & Figure 14 show how the spikes were cut and collected. Fresh and dry weight of shoots per m^2 was measured by cutting all the shoots from the soil surface. Shoots were placed in jute bags and air-dried for 30 days. The grain weight per m^2 was done by threshing the collected ears, whereas the thousand-grain weight was done after counting 1000 seeds. Both parameters were done with the generous help of *ICARDA* (International Center for Agricultural Research in the Dry Areas) in Lebanon. Ears were threshed by a *wintersteiger thresher LD 350* , as shown in Figure 15 and cleaned using *Kim seeds Cleaner MK3*, as shown in Figure 16. The clean seeds were weighed and recorded as (grain weight per m^2). Figure 17 shows the seed counter machine (*Pfeuffer Contador*).

Figure 13. *Cutting spikes of triticale*

Figure 14. *The collected spikes*

Figure 15. *Agricultural thresher machine*

Figure 16. *Seed cleaner machine*

Figure 17. *Seed counter machine*

3.11. Grain content analysis

Grain content analysis was done at the feeds and feeding lab at AUB under the supervision of Dr. Housam Shaib using *NIRS DS2500 at* the wavelength area of 400 – 2500 nm (*FOSS analytical solutions for food analysis and quality control*). The analysis included moisture, protein, fat, crude fiber, ash, and starch content of seeds.

3.12. Grain morphology measurements

The analysis included measuring morphological traits, which are: area, perimeter, major and minor axes of the best fit ellipse (length and width of seed) using specialized software from an image captured with consumer-level flatbed scanners in a robust in a standardized way. This analysis was done at ICARDA according to Whan *et al*. (2014) by using specialized seed scanner, as shown in Figure 18.

Figure 18. *Seed scanner*

3.13. Statistical analysis

Statistical analyses for both experiments was performed using IBM SPSS Statistics 25. Treatment means were compared using three-way ANOVA (analysis of variance) and Bonferroni test. Differences were considered significant at $\alpha = 0.05$. In other words, confidence level was 95%. The analysis was done by depending on syntax code of SPSS software under supervision of Dr. Samer Kharroubi.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter provides the overall analysis and results achieved in this study and it is divided into four parts. The first part includes the results of soil analysis, whereas the second part presents the supplemental irrigation program. The third part gives information about the chronic order of the data collection including the dates of applying supplemental irrigation and the last part provides the results and discussion of the collected data by analyzing and comparing them with previous studies related to this experiment.

4.1. Soil analysis

Table 19 and 20 show the soil analysis results and the ratio of nitrogen nitrate and total nitrogen, respectively. Analysis shows that the soil is heavy and rich with clay, calcium and other elements. According to Bashour (2001) the ratio of nitrogen, phosphorus and potassium in the tested soil is high (Table 21). Nitrate above 40 mg/kg in the soil is considered high. Also, phosphorous and potassium are considered high since their ratio is between 4-20 mg/kg and 250-450 mg/kg, respectively (Table 19).

Table 19. *Summary of soil analysis results*

Parameters	Results
Clay (%)	53.64
Sand (%)	9.33
Silt (%)	37.0
EC (µS/cm)	245
PH	7.36
Total $CaCO_3$ (%)	30.80
Organic Matter (%)	3.97
Available Potassium (mg/kg)	742 ppm =742 mg/kg
Available Phosphorous (mg/kg)	20 ppm = 20 mg/kg
Nitrogen-Nitrates (Wet Weight) (mg/kg)	<50
Total Nitrogen (%)	0.16

Table 20. *Ratio of Nitrogen-Nitrate and total Nitrogen in the soil*

Analysis	LOQ (Minimum Limit of Quantification)	Sample Result	Method
Nitrogen-Nitrates (Wet Weight)	50 mg/kg	<50 mg/kg	TC WI € M Spectrophotometer HACH 8039 M
Total Nitrogen (%)	0.05%	0.16%	ASTM E1019 M & Themofinnigan-High combustion

Table 21. *Nutrient range in soils, mg/kg*

Nutrient	Very low	Low	Medium	High	Very High
Nitrate, NO_3-N	0-5	5-15	15-30	30-40	>40
Phosphorous	0-3	3-8	8-14	4-20	>20
Potassium	0-85	85-150	150-250	250-450	>450

Adapted source: (Bashour, 2001)

4.2 Irrigation applications

According to the weather station at AREC, the sum of rain precipitation from 0 DAP to 255 DAP (harvesting) was 347.10 mm. Thus, the allocated field for supplemental irrigation received 170 mm above to 347.10 mm from the rain (Total of 517.10 mm).

Supplemental irrigation was carried out after 148, 157 and 172 DAP. Table 22 shows a summary information of the precipitation from both rain and supplemental irrigation system. Martyniak (2008) indicated that wheat, barley and triticale need between 293 and 314 mm of water during the growing season which is less or similar to the Beqaa plain.

Table 22. *Summary data of precipitation from rain I and supplemental (S) irrigation system*

Supplemental irrigation	DAP	R (mm)	S (mm)	Total of precipitation(mm) of supplementary irrigation and rain
S1	148	346.60	51.00	397.60
S2	157	0.00	68.00	68
S3	172	0.50	51.00	51.50
Total	172	347.10	170.00	517.10

4.3 Data collection

The first data was collected after 90 DAP before the first application of supplemental irrigation. Therefore, the influential factor that effected on the first collected data was NPK and 30% of nitrogen fertilizer. The second data was collected after 157 DAP after the second application of nitrogen fertilizer (102 DAP) and after first and second supplemental irrigations (148 and 157 DAP) as shown in Table 23. Last data was collected after 215 DAP or at harvesting. Table 24 summarizes the data collection dates combined with date and quantity of precipitation from the rain and supplemental irrigation system.

Table 23. *Summary data of precipitation (mm) from rain I and supplemental (S) irrigation days after planting (DAP)*

S	DAP	R	S	Total
S1	148	346.60	51.00	397.60
S2	157	0.00	68.00	68.00
S3	172	0.50	51.00	51.50
Total	172	347.10	170.00	517.10

Table 24. *Summary data collection combined with date and quantity of precipitation from the rain and supplemental irrigation system*

DAP	R	S	Total
100	273.40	0	273.40
170	73.50	119.00	192.50
225	0.2	51.00	51.20
Total	347.10	170.00	517.10

4.4 Results and discussions

This part covers up the effect of various nitrogen rates under rain fed and supplementary irrigation on various growth parameters of triticale.

4.4.1 Effect on plant height, fresh weight, and dry weight

Nitrogen at all tested rates enhanced triticale plant height after 100 DAP in comparison to the control (Figure 19). Nitrogen at 160 kg/ha was the most effective treatment in enhancing the triticale height. It is worth mentioning that neither supplemental irrigation nor second application of nitrogen was applied before 100 DAP. The significance differences in crop height among nitrogen treatments in all the tested plots is unknown. There is a possibility that the soil is already rich with nitrogen or over-fertilized.

Supplementary irrigation increased crop height compared to the rain fed regardless of NPK or nitrogen applications after 170 DAP (Figure 20). However, supplementary irrigation with nitrogen at rates above 120 kg/ha significantly enhanced crop height in comparison to the control. Addition of nitrogen (Except at 80 kg/ha) did enhance crop height in comparison to the control under rainfed conditions. Best sustainable results were obtained with a single application of NPK and nitrogen at 40kg/ha under both systems. Thus, farmers should be advised to add a single application of NPK at planting or sequential application of nitrogen at 40 kg/ha.

Nitrogen at all tested rates with or without supplementary irrigation had no significant effect on crop height in comparison to the control or to the NPK treatment after 225 DAP (Figure 21). There was a big variation among all treatments under both irrigation systems. Many researchers investigated the negative effect of excessive nitrogen fertilizers on many parameters of cereal crops. For example, Yu-kui *et al*. (2012) found an adverse relationship between over-fertilizing of nitrogen and plant height of corn. Similar results were obtained in this experiment that led to an insignificant difference among nitrogen treatments.

Supplementary irrigation alone or with nitrogen fertilizer increased fresh weight of triticale plants in comparison to the rain fed system 170 DAP (Figure 22). However, there was no significant differences among nitrogen treatments under supplementary irrigation. The highest average of fresh weight was observed with nitrogen at 40 kg/ha under both irrigation systems. Triticale average shoot fresh weight was 286.38 g and 295.88 g under rainfed and supplementary irrigation respectively.

The results of shoot dry weight after 100 and 170 DAP under rainfed and supplementary irrigation are shown in Figure 23 and 24, respectively. Supplementary irrigation alone increased the shoot dry weight of triticale in comparison to the rainfed treatments (Figure 23). Unlike under rainfed, addition of nitrogen at various rates did not increase the shoot dry weight. Best shoot dry weight was recorded in the control under supplementary irrigation.

Figure 25 shows that supplemental irrigation with or without nitrogen applications had no significant effect on shoot dry weight after 170 DAP in comparison to the control. Except for nitrogen treatments above 160 kg/ha, shoot dry weight under both supplementary irrigation and rain fed conditions were similar. Similar results were obtained under rainfed or supplementary conditions with nitrogen. Thus, irrigating at this time will have no added value on the crop and will be a waste of water and extra cost for the farmers. However, there was a significant difference in the dry weight under NPK under the rain fed conditions. Overall, the highest shoot dry weight was with NPK under rain fed (107.45 g) and nitrogen at 120 kg/ha under supplemental irrigation (97.98 g).

Our results are similar to studies conducted by Alagoz *et al*. (2021) which aimed to study the effects of water deficit on various phenological stages of triticale. They found that water stress reduced triticale plant dry weight by 24% at the heading stage, 33.5% at the flowering stage, and 12.3% at the kernel stage, while the highest dry weight was recorded under supplemental irrigation conditions. To sum up, according to previous studies, the water regime is the most influential factor on triticale growth compared to fertilizers (Barati *et al*., 2020; Tas & Tas, 2007).

Results in figure 25 show that addition of nitrogen at all tested rates had no significant effect on triticale shoot dry weight under both irrigation systems after 100

DAP. Aciksoz *et al*. (2011) reported that application of nitrogen improved the total shoot dry weight by 42% and shoot iron content in wheat. Also, Tóth *et al*. (2021) found that a combination of low nitrogen and low phosphorous reduced tillers number, plant height, seeds number, fresh and dry weight of seeds in wheat.

Figure 19. *Average of plant height (cm) of triticale under rainfed I and supplemental irrigation (S) systems after (100 DAP) ± SE, (n=80 plants)*

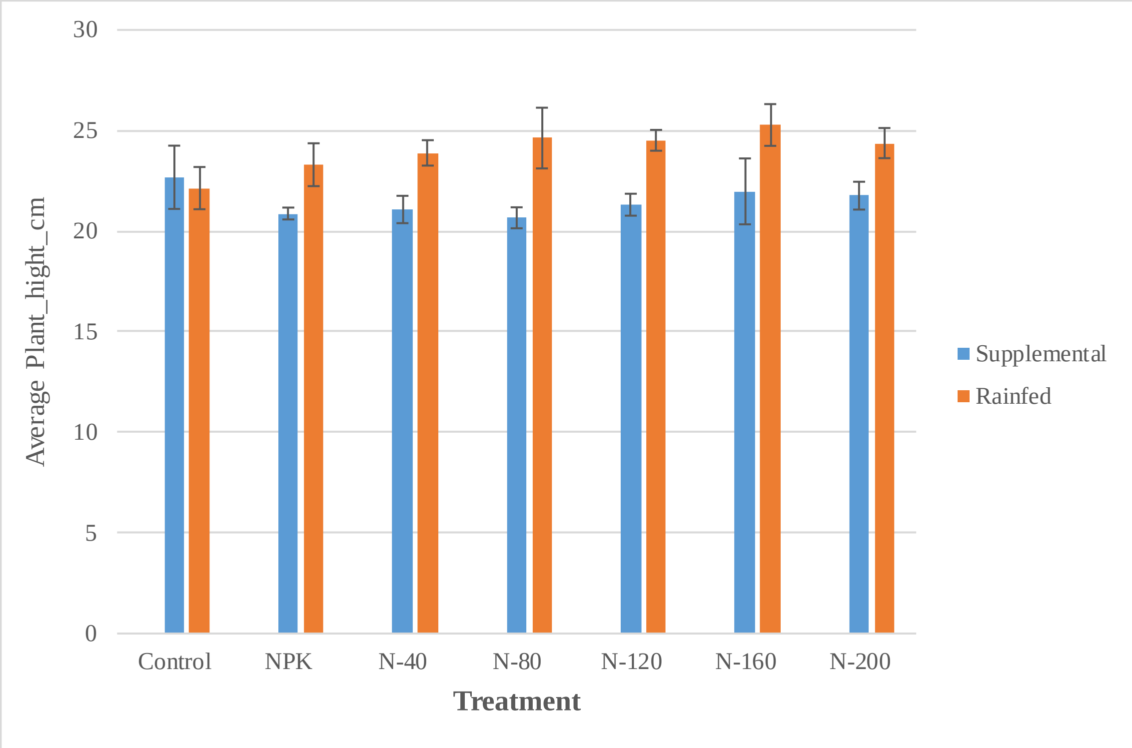


Figure 20. *Average of plant height (cm) of triticale under rainfed I and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants)*

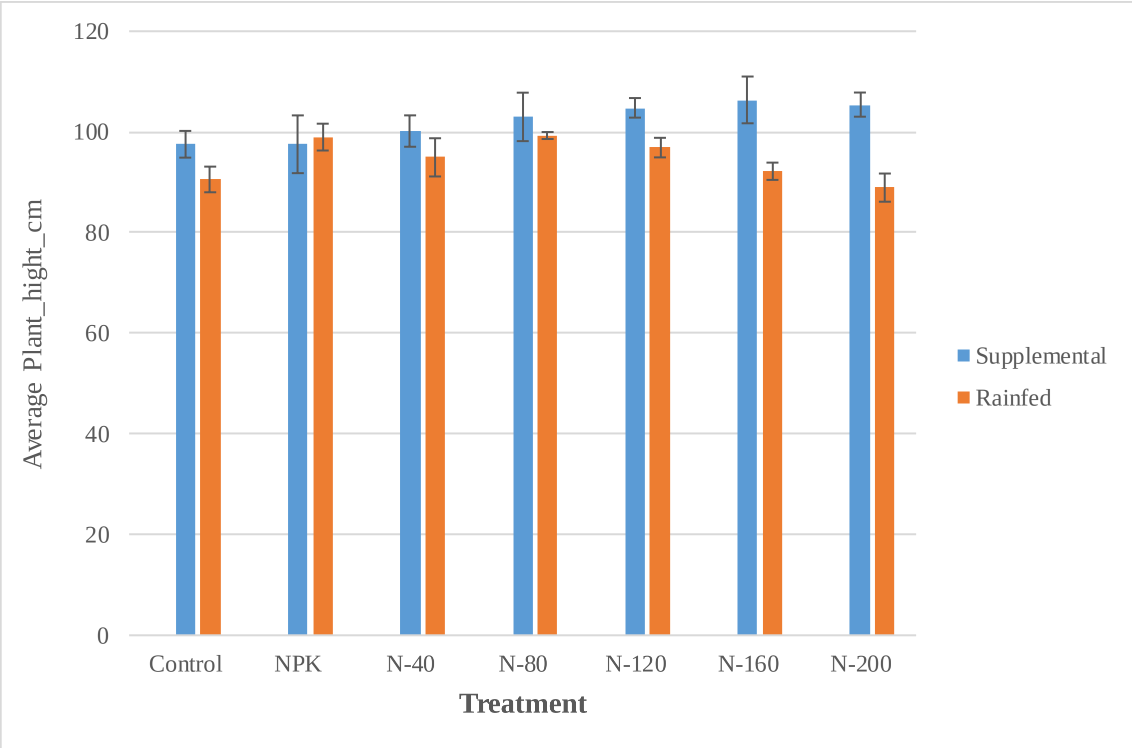


Figure 21. *Average of plant height (cm) of triticale under rainfed I and supplemental irrigation (S) systems after (225 DAP) ± SE, (n=80 plants)*

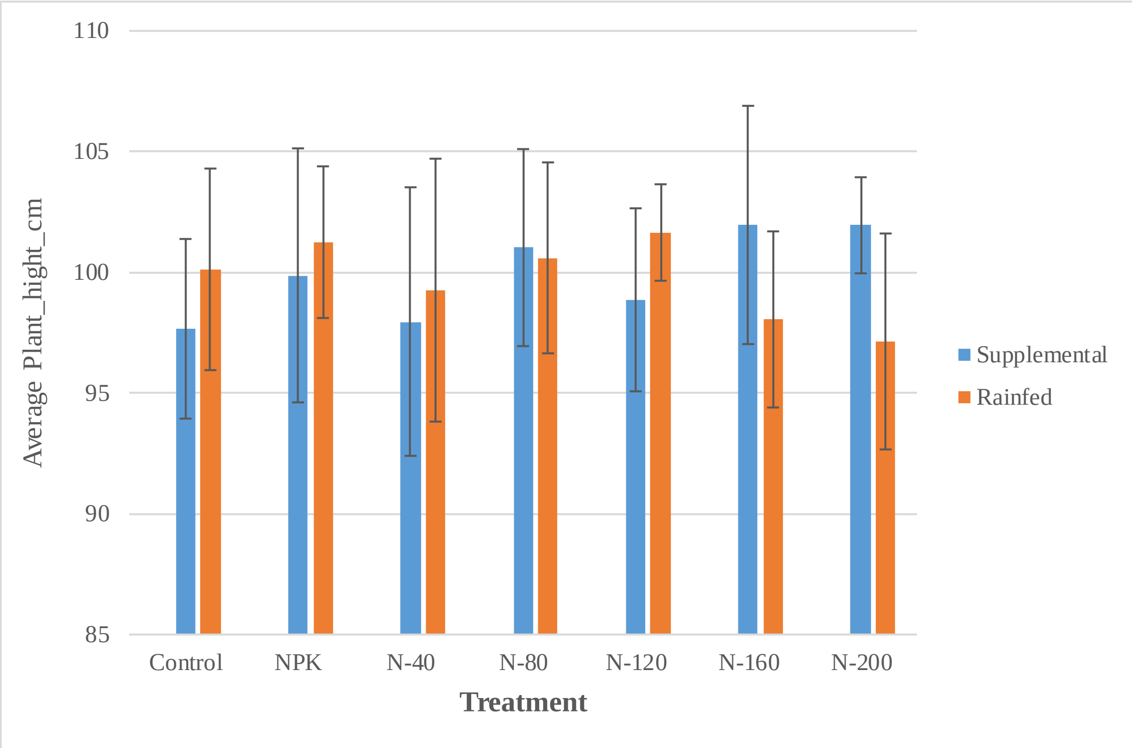


Figure 22. *Average of fresh weight (g) of triticale) under rainfed I and supplemental irrigation (S) systems after (170 DAP) ± SE, (n= 80 plants)*

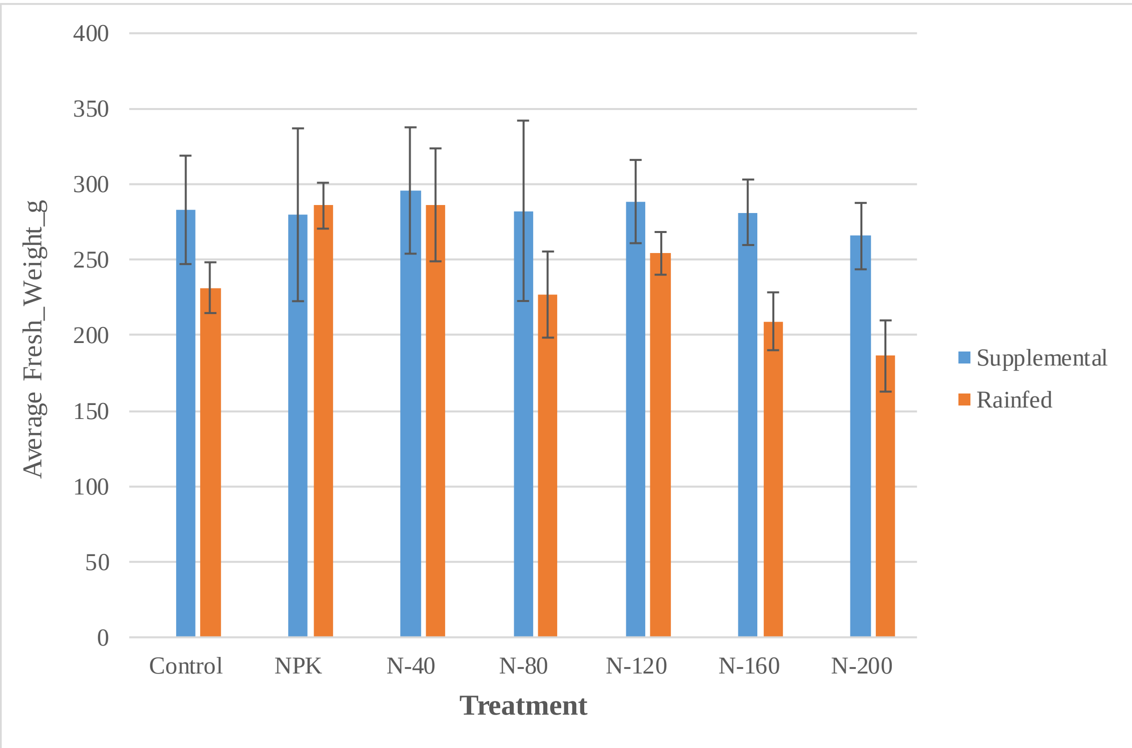


Figure 23. *Average of dry weight (g) of triticale under rainfed I and supplemental irrigation (S) systems after (100 DAP) ± SE, (n= 80 plants)*

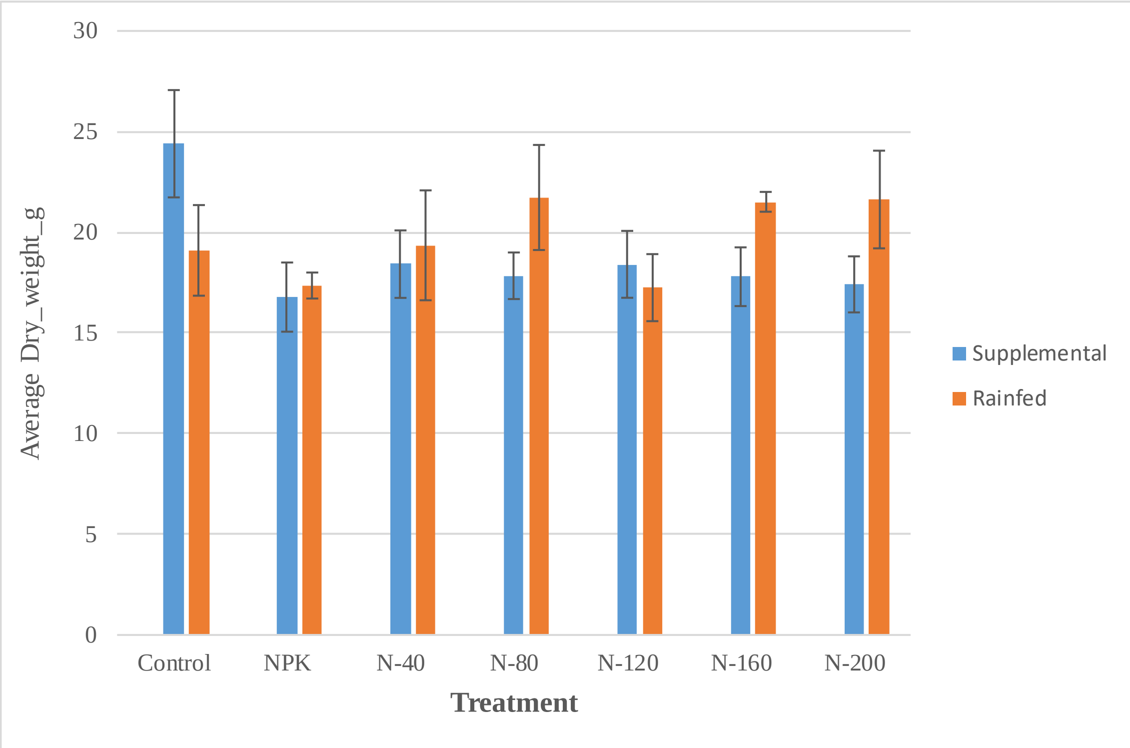


Figure 24. *Average of dry weight (g) of triticale under rainfed I and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants)*

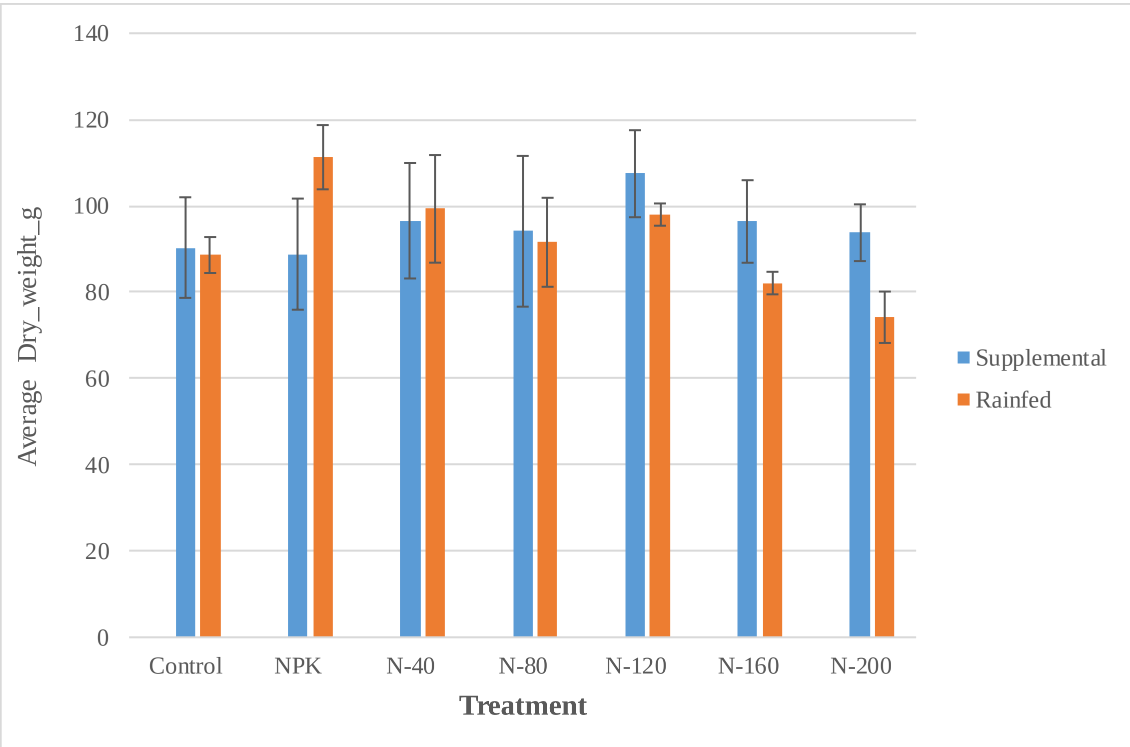
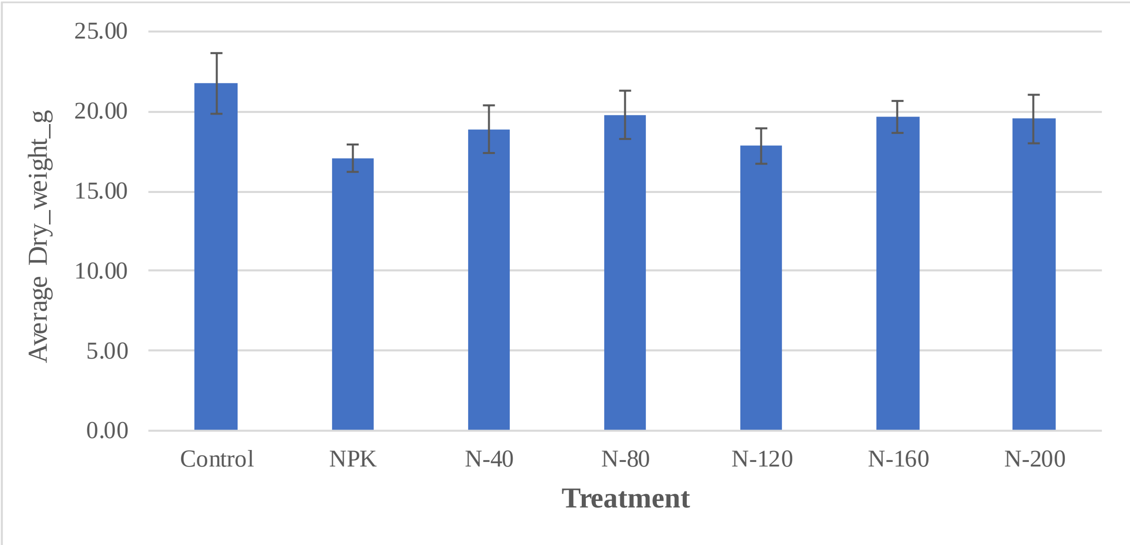


Figure 25. *Average of dry weight of triticale regardless the watering system after (100 DAP) ± SE, (n= 160 plants)*



4.4.2 Effect on grain weight

Results in Figure 26 show that the average grain weight of triticale under supplementary irrigation is higher than the rainfed regardless the addition of nitrogen fertilizer 225 DAP. Addition of nitrogen did not increase the grain weight of triticale in comparison to the control. Supplementary irrigation with or without nitrogen at all tested rates had the same effect on grain weight. Thus, supplementary irrigation is important to enhance grain weight during the growing season of triticale. The significant positive impact of the supplementary irrigation had appeared in all nitrogen fertilization treatments (except N-120) under supplemental irrigation treatments versus the same treatments under rainfed conditions. On the flipped side, there is no significant difference between the nitrogen fertilization treatments under supplemental irrigation system. Also, the same situation had been noticed under rainfed conditions. Overall, supplementary irrigation alone (control) produced the highest grain weight, while N-120 treatment under the same conditions produced the lowest, 642.05 and 534.28 g, respectively. On the other side, under rainfed conditions, the highest average grain weight was recorded by NPK treatment, whereas the control treatment produced the lowest, 497.83 and 404.00 g, respectively. Estimating the grain weight of triticale per one dunum and one hectare under the same situation of this experiment is summarized in Table 32 and 33.

Same trend could be concluded if we compare the average of thousand grain weight (Figure 27) with the grain weight/area (Figure 26). Low rates of nitrogen treatments significantly increased the weight of thousand seeds under supplemental irrigation compared to the rainfed treatments. Supplementary irrigation alone (Control) increased the grain yield. Moreover, the average thousand-grain weight for the control, NPK, N-40 and N-80 under supplemental irrigation system were similar and significantly higher than N-160 and N-200 treatments. N-160 treatment recorded the lowest average thousand-grain weight under supplemental irrigation system and rainfed conditions, 25.20 and 25.45 g, respectively. Overall, the control treatment gave the highest average thousand-grain weight under supplemental irrigation system, while NPK treatment was superiors under rainfed conditions, 31.13 and 27.80 g, respectively. The reason for reducing the grain weight per m^2 and thousand-grain weight under rainfed conditions in this study compared to supplemental irrigation systems could be due to drought stress and high temperatures during the grain-filling period, as it often occurs in Mediterranean conditions (Oweis *et al.*, 2000).

Various researchers reported that supplementary irrigation was the most influential factor that affected the grain weight of cereals. For instance, Barati *et al*. (2020) found that supplementary irrigation with N-150 significantly increased grain weigh of triticale. It should be noted that both adjacent fields of this experiment were planted lentils in 2019. Thus, addition of nitrogen may not enhance grain yield more than the control since lentils is a nitrogen fixer. Furthermore, many scientists reported that over-fertilizing with nitrogen could lead to impairment in root growth and exudation (Deng *et al*., 2014; Shen *et al*., 2013; Teng *et al*., 2013). Besides, many studies reported that nitrogen requirement in triticale is less than other cereal grains. For instance, Defra (2010) recommended that the nitrogen requirement for triticale should be around 150 kg/ha.

Figure 26. *Average of grain weight (g) of triticale per square meter under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4 m²)*

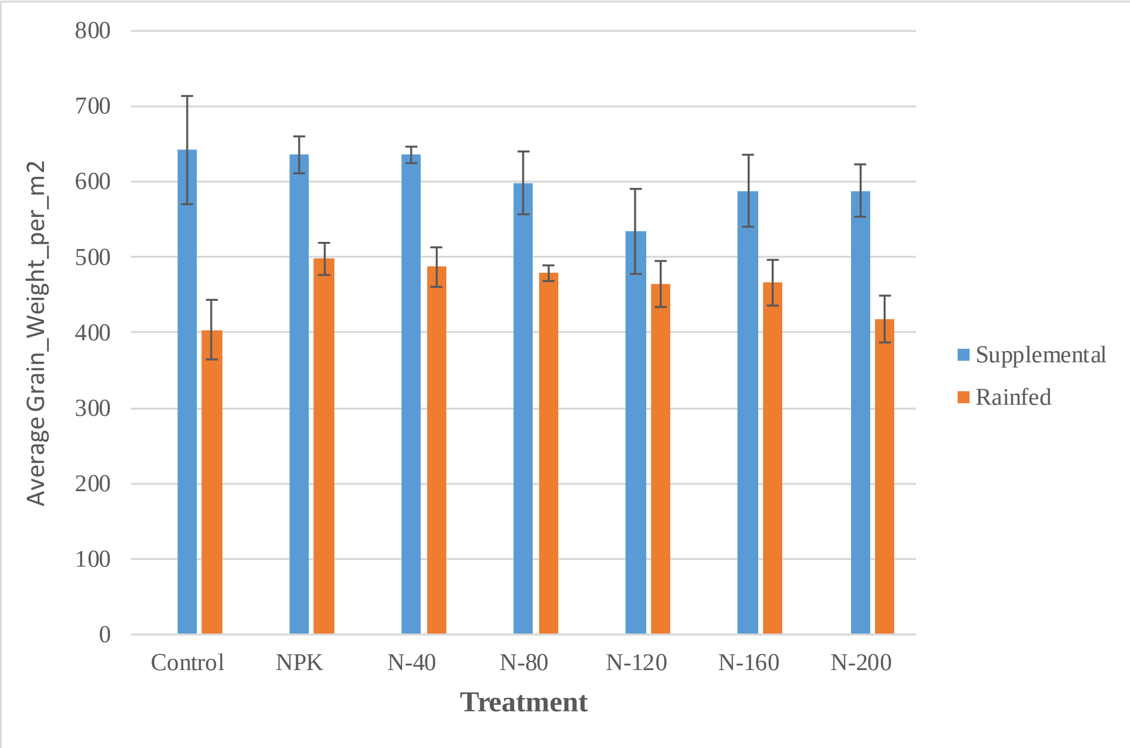
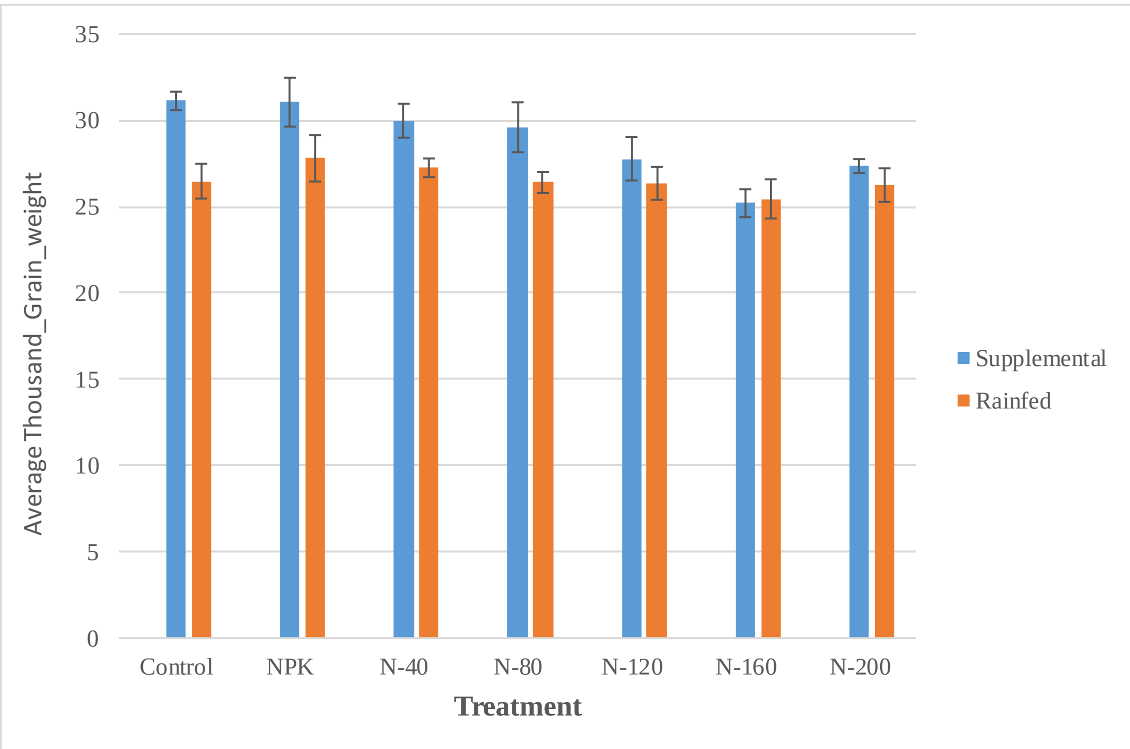


Figure 27. *Average of thousand grain weight (g) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4,000 seeds)*



4.4.3 Effect on grain weight regardless of the treatments of fertilization

The grain weight in both the supplemental irrigation and rainfed conditions, regardless of the nitrogen treatments was 5816.33 kg and 4914.29 kg/ha, respectively (Table 34). Higher yield was obtained under supplementary than rainfed system. Supplementary irrigation enhanced the yield in comparison to the rainfed system regardless the nitrogen application. Mergoum and Macpherson (2004), reported that the average grain yield of triticale is around 2.5 t/ha under rainfed conditions and could be exceeded 7 t/ha under irrigated conditions (Fohner & Sierra, 2004). The grain yield of triticale differs among countries between less than 1 t/ha in lower rainfall poor soil and more than 7 t/ha in higher rainfall good soil. According to FAO (2019), the highest yield of 6.6122 t/ha was recorded in Belgium and the lowest yield of 1.285 ton/ha in Australia. In Africa, Tunisia and Algeria recorded the yield of 1.9527 t/ha and 2.0667 t/ha, respectively (Table 1).

Martyniak (2008) declared that triticale needs an average of between 300mm of water. Based on weather data at AREC, the sum of rain precipitation during the growing season of triticale was 347.10 mm. Thus, the water needed by triticale growth was sufficient during the growing season. Accordingly, high yield was obtained under rainfed conditions.

4.4.4 Effect on spike weight and spike number per square meter

Figure 28 shows that spike weight collected 225 DAP under supplementary irrigation with or without NPK or nitrogen fertilizers was higher than the rainfed system. Our statistical analysis showed that the different quantities of nitrogen fertilizer did not make a significant increase in spike weight in comparison to the control. Spike weight was slightly higher under nitrogen at 40 kg/ha under supplementary irrigation, comparing to all other treatments. Addition of NPK and nitrogen at 40 to 160 kg/ha under rainfed conditions significantly increased spike weight in comparing to the control.

Figure 29 shows that all nitrogen treatments with or without supplementary irrigation did not increase spike number. Nitrogen at 120 kg/ha under the supplemental irrigation system and nitrogen at 80 kg/ha under rainfed conditions gave the highest spike number ranging between 503.75 and 526.50, respectively. Contrarily, control treatment under both supplemental irrigation system and rainfed conditions gave the lowest spike number, 443.00 and 446.25, respectively (Table 36 and Figure 29). Our observations were similar to those of Bielski *et al*. (2020), that spike number was higher under various rates of nitrogen fertilizer.

Figure 28. *Average of spike weight (g) of triticale per square meter, under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4 m^2)*

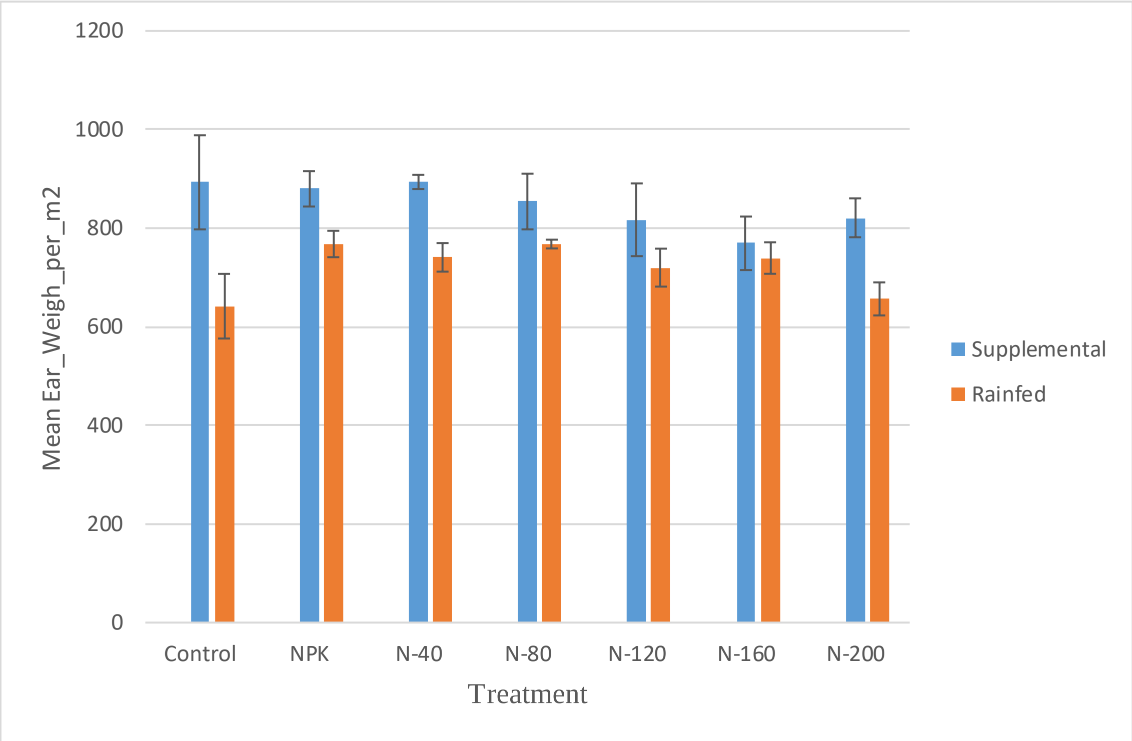
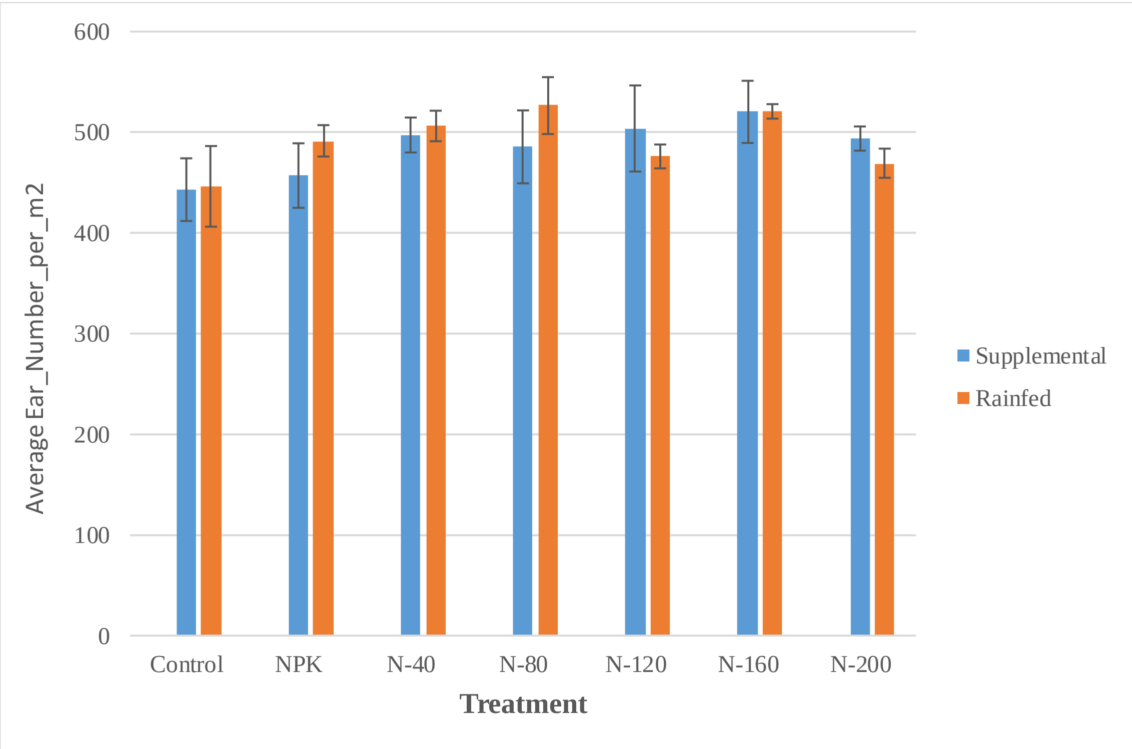


Figure 29. *Average of spike number of triticale per square meter, under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4 m^2)*

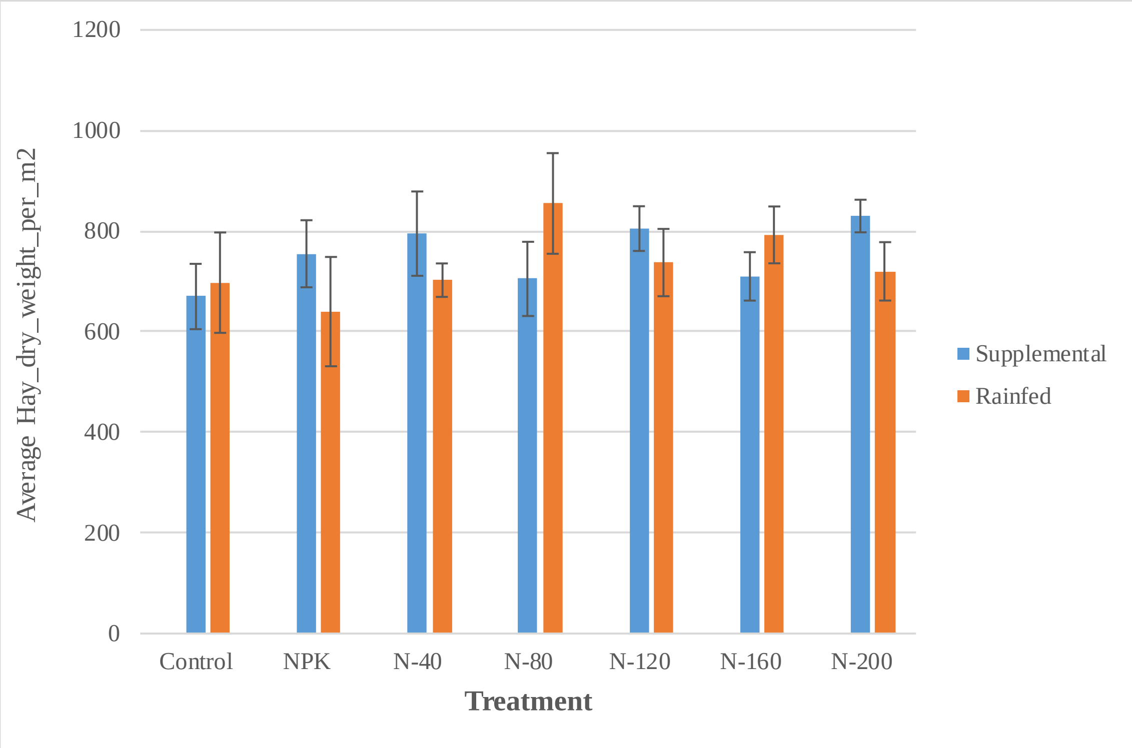


4.4.5 Effect on hay dry weight

The effect of various rates of nitrogen on hay dry weight varies between supplementary irrigation and rain fed (Figure 30). Neither nitrogen treatments with or without supplementary irrigation, nor supplementary irrigation alone enhanced hay dry weight. No significant differences were found among hay dry weight between the nitrogen treatments under supplemental irrigation or rainfed conditions. Also, there is no significant difference between the nitrogen fertilization treatments under both irrigation systems. Nitrogen at 80 kg/ha gave the highest hay dry weight (855g) under rainfed conditions. On the other hand, the lowest hay dry weight under rainfed and supplemental irrigation conditions was recorded under NPK and the control treatments, 640 g and 697.50 g, respectively (Table 37 and Figure 30).

Many studies indicated that hay dry weight could be increased by nitrogen fertilizers. Grunow *et al.* (1970) indicated that "There cannot be any doubt that high nitrogen increases the nitrogen content of herbage and hay, but it must be borne in mind that differences in species composition play apart also". The same applied to the addition of water on hay production of *Lathyrus sativus* (Safi *et al.*, 2013).

Figure 30. *Average of hay dry weight (g) of triticale stem per square meter under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4 m²)*

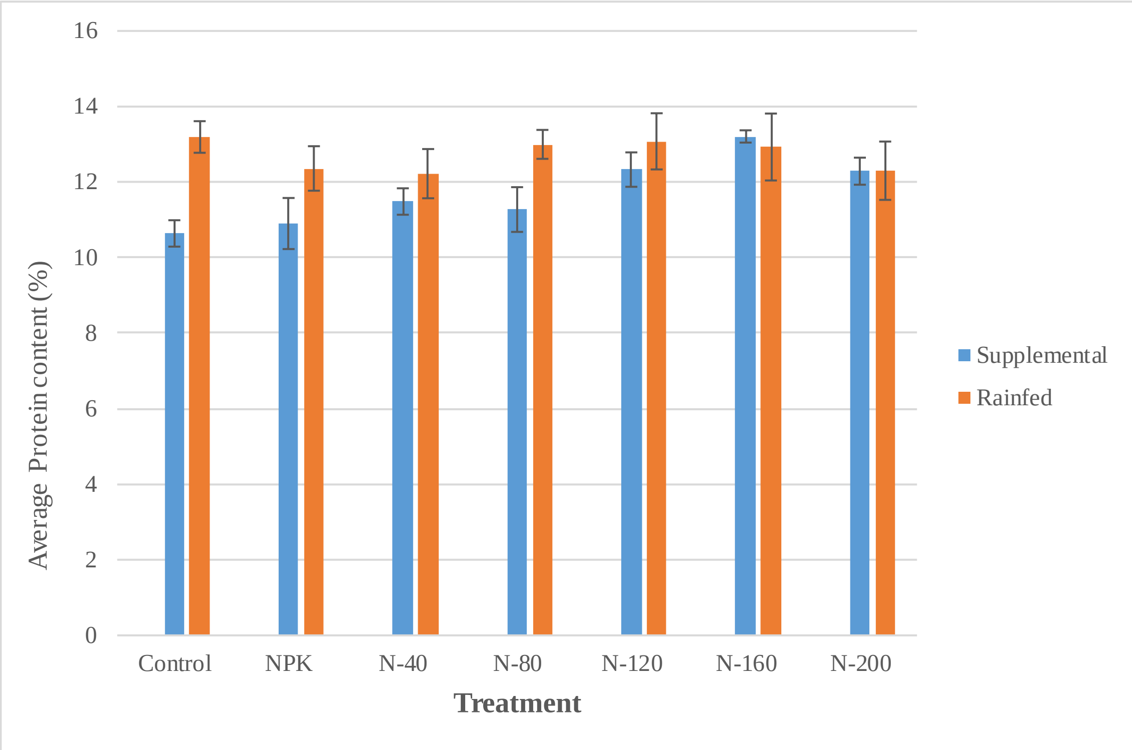


4.4.6 Effect on grain content

4.4.6.1 Effect on grain protein content

Our analysis showed that nitrogen at all tested rates did not increase the grain protein content under rain fed condition while they did under supplementary irrigation in comparison to their respective controls (Figure 31 and Table 38). The most effective treatment that gave the highest grain protein content was recorded in the control under rainfed and with nitrogen at 160 kg/ha under supplementary irrigation. Both treatments increased grain protein content by around 13.20%. The reason of higher protein content under rainfed alone than the same treatment under supplemental irrigation could be related to the impact of water stress on the crop which could activated the movement of nitrogen from the leaves to the grains, leading to an increase in protein content in the grains (Souza *et al.*, 2004).

Figure 31. *Average of grain protein content (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

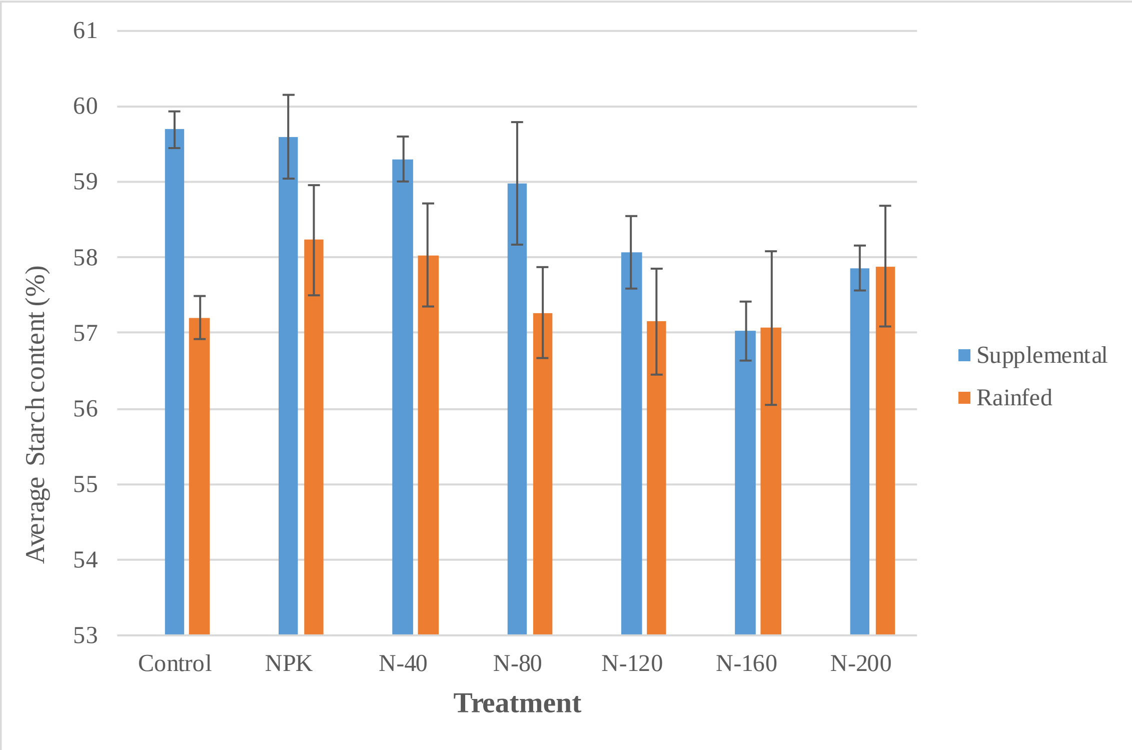


4.4.6.2 Effect on grain starch content

The grain starch content under supplementary irrigation with or without nitrogen was higher than the rain fed treatments (Table 39 and Figure 32). Addition of nitrogen fertilizers did not enhance starch content in the grains under rain fed condition. Our results show a negative relationship between grain starch content and protein content under supplemental irrigation system, as summarized in Table 40, Figure 31 &32. For example, control treatment under supplemental irrigation system accounted for the smallest ratio of grain protein content, while it recorded the highest grain starch ratio, 10.64 and 59.69 %, respectively. Our results also show a steady decrease of starch content combined with an increase in nitrogen rate application under supplemental irrigation system and vice versa for grain protein content. Regarding rainfed conditions, there could be a negative relationship between grain starch and protein content, but most treatments recorded a high ratio of grain protein content and a low ratio of starch content (Table 40, Figure 31 & 32).

Silva *et al*. (2020) indicated that carbohydrate content in the evaluated cultures showed variation in results concerning the water regime and differed inversely to the protein content. One of the most familiar symptoms of the impact of drought on the plant is the decrease in the grain starch content, which has been considered the primary form of carbohydrate storage in cereals (Thitisaksakul *et al.*, 2012). In most cases, low grain starch has been found to be associated with water stress, leading to a negative impact on photosynthesis as the availability of water is essential for it (Flagella *et al*., 2010).

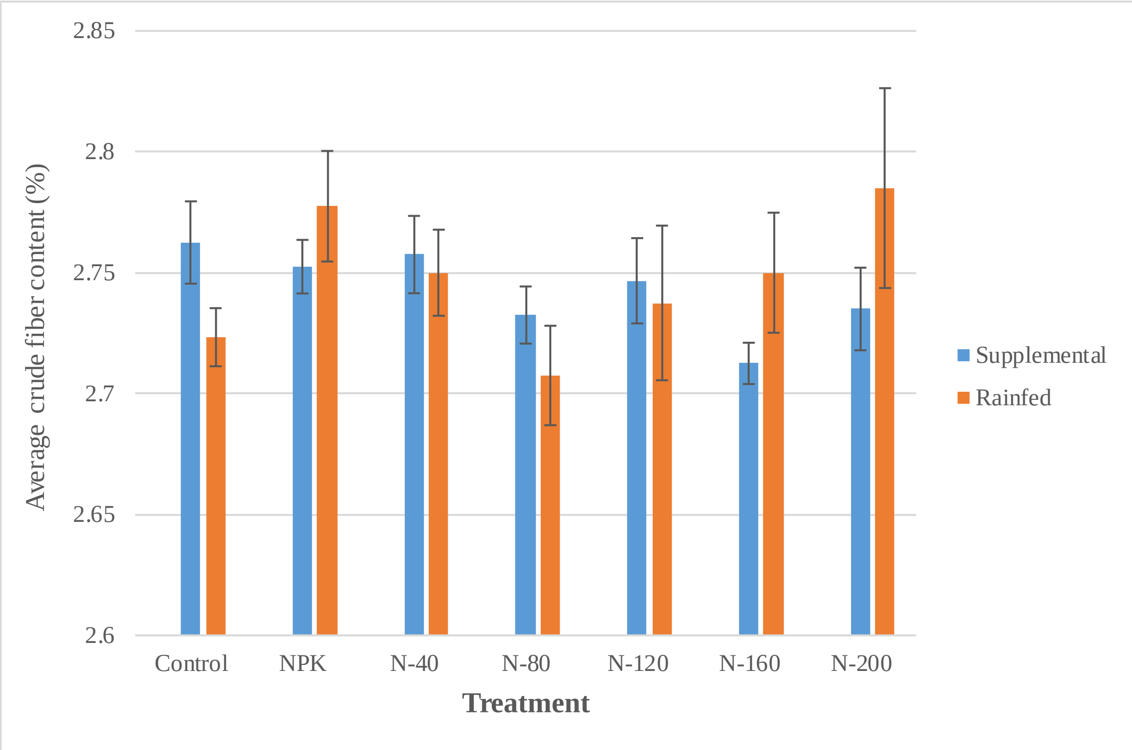
Figure 32. *Average of grain starch content (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE (n=4,000 seeds)*



4.4.6.3 Effect on grain crude fiber content

The grain crude fiber content varied among treatments regardless supplementary irrigation (Figure 33 and Table 41). Addition of nitrogen and/or water did not significantly increase the grain crude fiber content. The grain crude fiber content under all nitrogen treatments under both supplementary irrigation and rainfed conditions recorded similar results. However, the highest recorded grain crude fiber content under the supplemental irrigation was in control and with nitrogen at 40 kg/ha treatments (same ratio 2.76%), while nitrogen at 160 kg/ha treatment was the lowest (2.71 %). On the other hand, the highest recorded grain crude fiber content under rainfed conditions was by nitrogen at 200 kg/ha. Besides, it reduced milling yield, which is perhaps due to expanded fiber content and decreased kernel weight under such conditions.

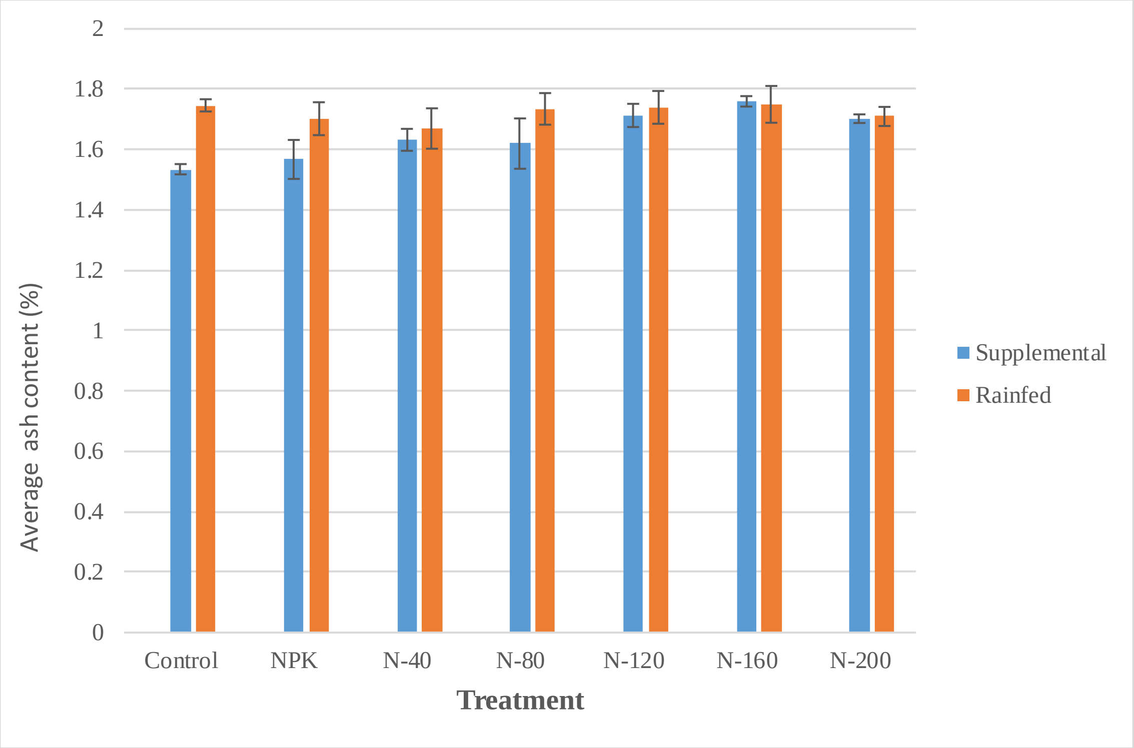
Figure 33. *Average of grain crude fiber content (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE (n=4,000 seeds)*



4.4.6.4 Effect on grain ash content

Supplementary irrigation with or without nitrogen did not increase the grain ash content of grain in comparison to all rain fed treatments (Table 42 and Figure 34). All tested rates of nitrogen significantly increased the grain ash content under supplementary irrigation in compassion to the control. Nitrogen at 160 kg/ha gave the highest grain ash percentage under supplementary irrigation and rainfed conditions ranking, 1.76 and 1.75, respectively. Many studies showed that the ash content of triticale was higher under rainfed conditions than various irrigated systems. Also, it was noted that the ash content significantly decreases as nitrogen increases. For example, Barati and Bijanzadeh (2021) concluded that there was a significant decrease in grain ash of triticale as nitrogen increased to 150 kg/ha under various irrigation regimes.

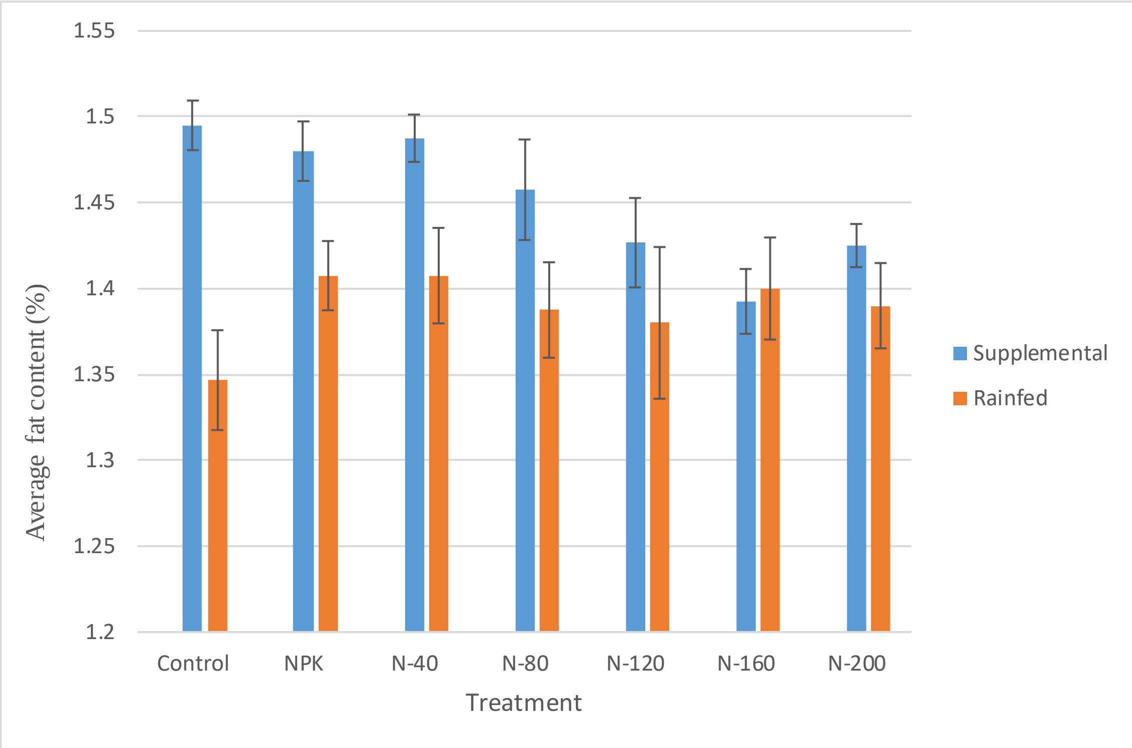
Figure 34. *Average of grain ash content (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*



4.4.6.5 Effect on grain fat content

Our results show that the grain fat content was higher under supplementary irrigation with or without nitrogen in comparison to all treatments under rainfed conditions (Figure 35 and Table 43). NPK, nitrogen at 40 and 80 kg/ha and the control significantly increased grain fat content under supplementary irrigation in comparison to the same treatments under rainfed. All these treatments increased the grain fat content. The highest grain fat percentage was observed in the control under supplementary irrigation. All rates of nitrogen had no significant effect on grain fat content in comparison to the control under the rainfed conditions. Increasing nitrogen did not increase grain fat content under rain fed conditions. Our results show an approximately gradual decrease of grain fat content combined with an increase in nitrogen rate under supplemental irrigation system. It was difficult to correlate a relationship between grain fat content and the increase of nitrogen rate due to the large variation among all treatments under rain fed conditions.

Figure 35. *Average of grain fat content (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n= 4,000 seeds)*



4.4.6.6 Effect on grain moisture content

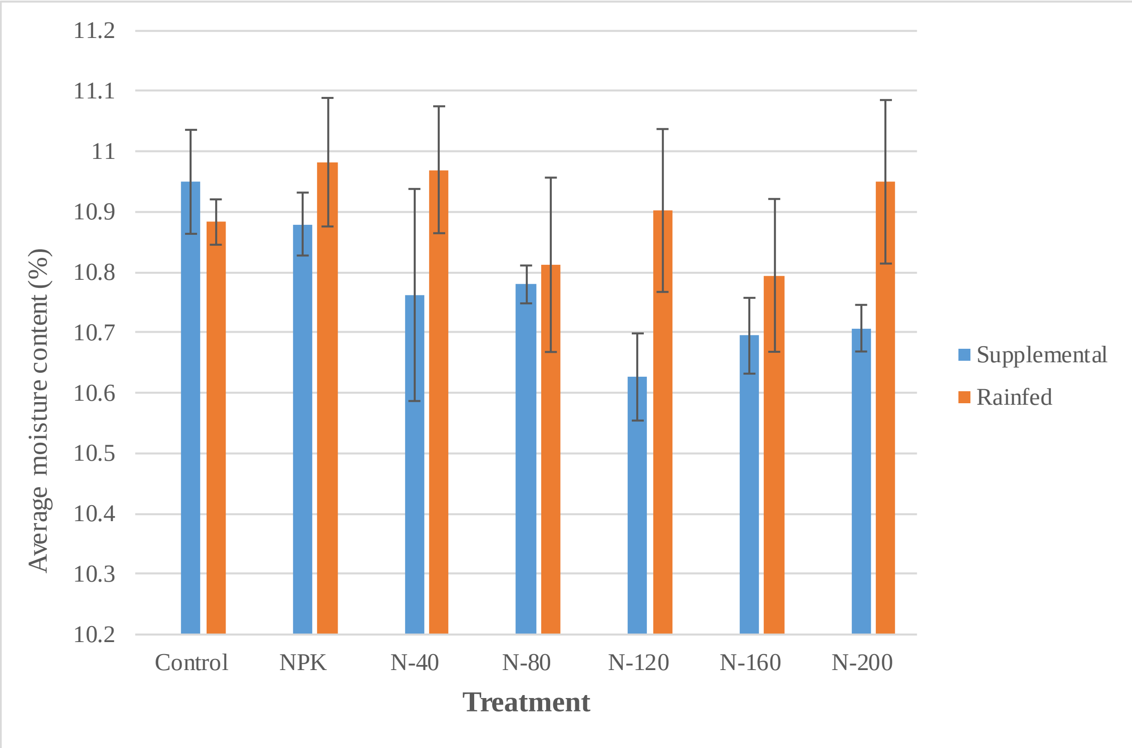
Application of nitrogen at all tested rates increased the grain moisture content under rain fed, compared to the supplementary irrigation Figure 36 and Table 44). All tested rates of nitrogen did reduce the grain moisture content under supplementary irrigation in comparison to the rain fed treatments. Except for nitrogen at 120 kg/ha, the average moisture ratio for all treatments under both supplementary irrigation and rainfed conditions were similar and ranged between 10.63 and 10.98 %.

Seed moisture content has been considered a strong factor in the reduction of seed longevity during storage. Many studies indicated that high seed moisture content was the most significant factor affecting seed deterioration, hastening insect, and fungal infestation and thus it is considered the most important factors that mediate seed quality and seed shelf life (Afzal *et al.*, 2019). The grain moisture content of the most agronomic crop should not exceed 13% for long storage (Abass *et al.*, 2014). Higher grain moisture content combined with high temperature could be a suitable conditions for the multiplication and growth of microorganisms (McDonald, 2007). Our results show that the grain moisture content under of all treatments under rainfed and supplemental irrigation systems was below 11%.

According to various studies about the effect of different water regimes on the grain moisture content, and according to our knowledge, many of them did not present evidence that supplied irrigation could impact grain moisture content. For example, Karim *et al*. (2000) experimented with the response of the grain moisture content of wheat under rainfed and regular irrigated conditions. They concluded that water stress treatments did not affect the dynamics of grain moisture content.

Regarding the impact of different nitrogen fertilizers on the grain moisture content, few studies have reported the effect of nitrogen applications on the grain moisture content.Svečnjak *et al*. (2020) showed that the highest grain moisture content (45%) of Italian ryegrass was noted at nitrogen rate of 180 kg/ha. Grain moisture at nitrogen application at the rates of 120 and 180 kg /ha were 44% and 42%, respectively. Our results are consistent with the result of Zhang *et al*. (2021) who found that nitrogen application has a slight effect on grain moisture content of corn.

Figure 36. *Average of grain moisture (%) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*



4.4.6.7 Correlation between the grain components

Our data results show a negative relationship between grain protein and starch content and a positive relationship between grain protein and fat content. This is in agreement which studies carried out by Janusauskaite et al. (2019). Svihus and Gullord (2002) supported evidence from previous observations of our experiment regarding the positive relationship between grain starch and fat content and the negative relationship between grain protein content and between the mentioned components. Also, there was a positive relationship between grain protein and moisture content and a positive relationship between grain protein and ash content.

Our results are consistent with studies done by Katyal *et al.* (2016); Müller *et al.* (2021); Samol *et al.* (2015); and Wahbi and Shaaban (2011).

4.4.7 Effect on grain morphology

Measurements of grain morphology was done at the International Center for Agricultural Research in the Dry Area (ICARDA) in Lebanon using the Grainscan software (Whan *et al*., 2014). Previous studies that relied on this method were not related to the impact of nitrogen applications and water regimes on triticale growth and development. Therefore, this is the first study that adopted this software to define the impact of different quantities of nitrogen fertilization and watering systems on the grain morphology of triticale. The morphological measurements include:

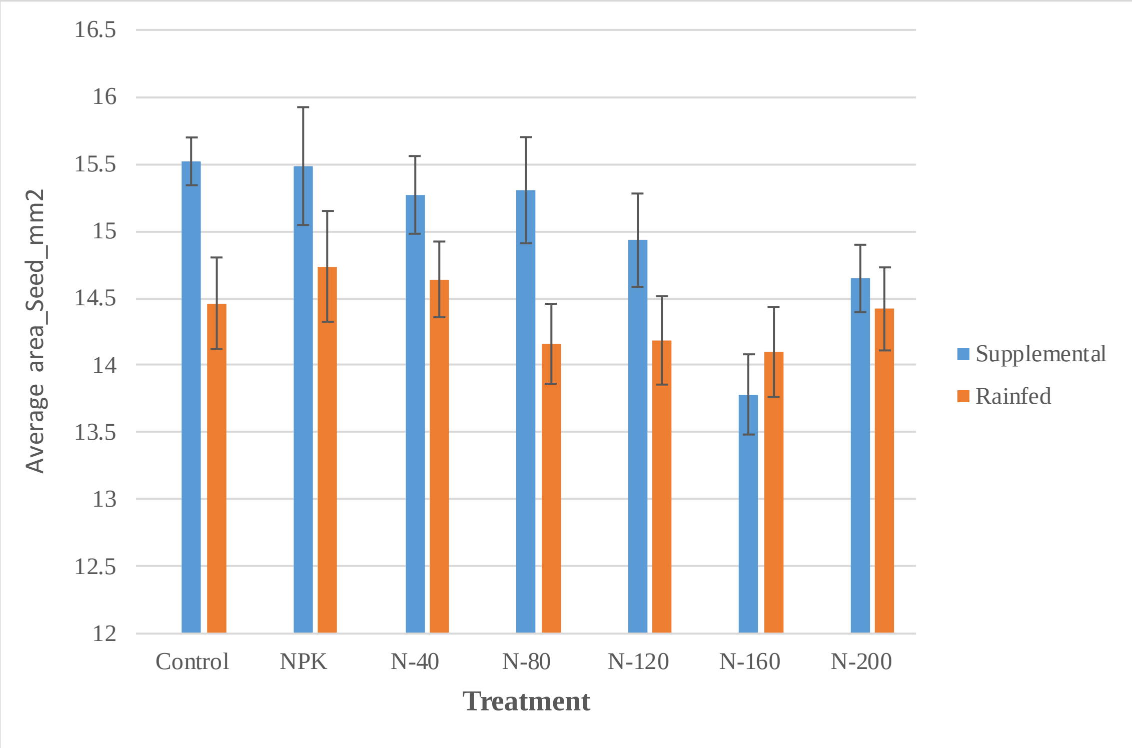
4.4.7.1 Grain area

Except for nitrogen treatment at 160 kg/ha, supplementary irrigation alone or with nitrogen at all tested rates increased the grain area of triticale in comparison to the same treatments under rain fed (Figure 37 and Table 45). Supplementary irrigation alone significantly increased the grain area in comparison to all nitrogen treatments under rainfed or supplementary irrigation. Overall, the control treatment under supplemental irrigation system yielded the highest average grain area, whereas NPK yielded the highest under rainfed conditions, 15.52 and 14.74 mm^2, respectively.

Grain area is a better predictor of grain weight than length and width of grains (Kim *et al*., 2021). In our study, it would appear that there is a positive relationship between grain area and grain weight of triticale. In other words, there is a positive relationship between grain area and both grain weight/area and thousand-grain weight of triticale (Table 46 & Table 47). For example, the grain area of control treatment under supplemental irrigation and rainfed systems was 15.52 and 14.46 mm^2, respectively. In comparison the grain weight/area and thousand grain weight under supplemental irrigation system were 642.05 g and 31.13 g, respectively, while they were 404.08 g and 26.48 g, respectively under rain fed.

Based on these results, we could conclude that grain area is a good indicator for estimating grain weight. The concept of predicting grain weight based on grain area has been investigated by many researchers. Table 48 provides information from three experiments about average grain weight and grain area of wheat (Brinton et al., 2017; Sanchez-Bragado et al., 2020; Wang et al., 2018). It has been clear that the lowest range in average grain area had led to the lowest range in average grain weight, as reported by (Wang *et al*., 2018). On the other hand, an increase in the range of average grain area led to an increase in grain weight, as provided by Sanchez-Bragado *et al*. (2020) and Brinton *et al*. (2017).

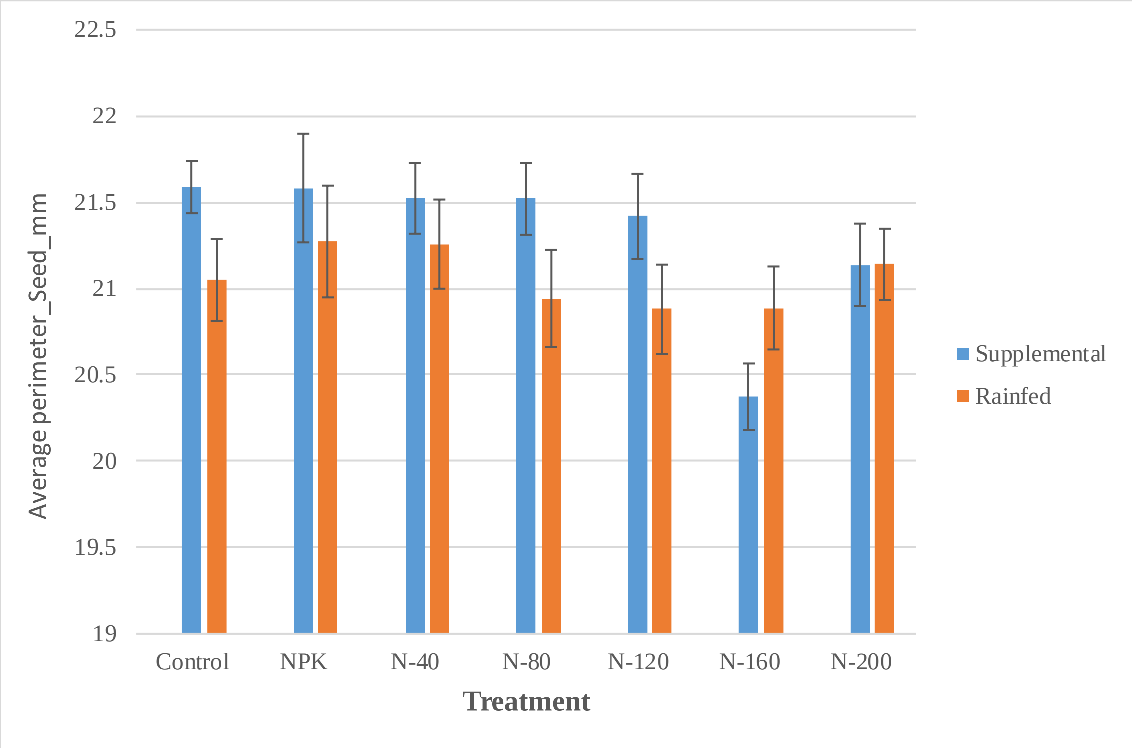
Figure 37. *Average of grain area (mm^2) of triticale under rainfed I and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*



4.4.7.2Grain parameter

Except for |nitrogen at 160 kg/ha, supplementary irrigation with or without nitrogen at all tested rates increased the grain parameter in comparison to the same treatments under rainfed conditions (Table 49 and Figure 38). Nitrogen at 160 kg/ha under rainfed conditions was slightly higher than the same treatment under supplemental irrigation system, 20.89 and 20.37 mm, respectively. Table 50 and 51 show that the highest grain perimeter was under the supplemental irrigation system without nitrogen fertilizer or the control (21.59 mm). This treatment also recorded the highest grain weight and thousand-grain weight under the same water regime, 642.05 and 31.13 g, respectively. On the other side, NPK treatment was very effective in increasing grain parameter (21.27 mm), compared to all nitrogen fertilization treatments. It seems there is a positive relationship between grain weight and grain parameter under rainfed conditions. Grain weight was higher under rainfed condition compared to the same treatments under supplementary irrigation. Gao *et al*. (2021) showed a positive relationship between grain perimeter and grain weight in wheat. Their results show that when the average grain perimeter of wheat was 15.99 mm the average grain weight of wheat was 42.77 g.

Figure 38. *Average of grain parameter (mm) of triticale, (n=1000 seed ×4 replicates) ± SE, under rainfed I and supplemental irrigation (S) systems*



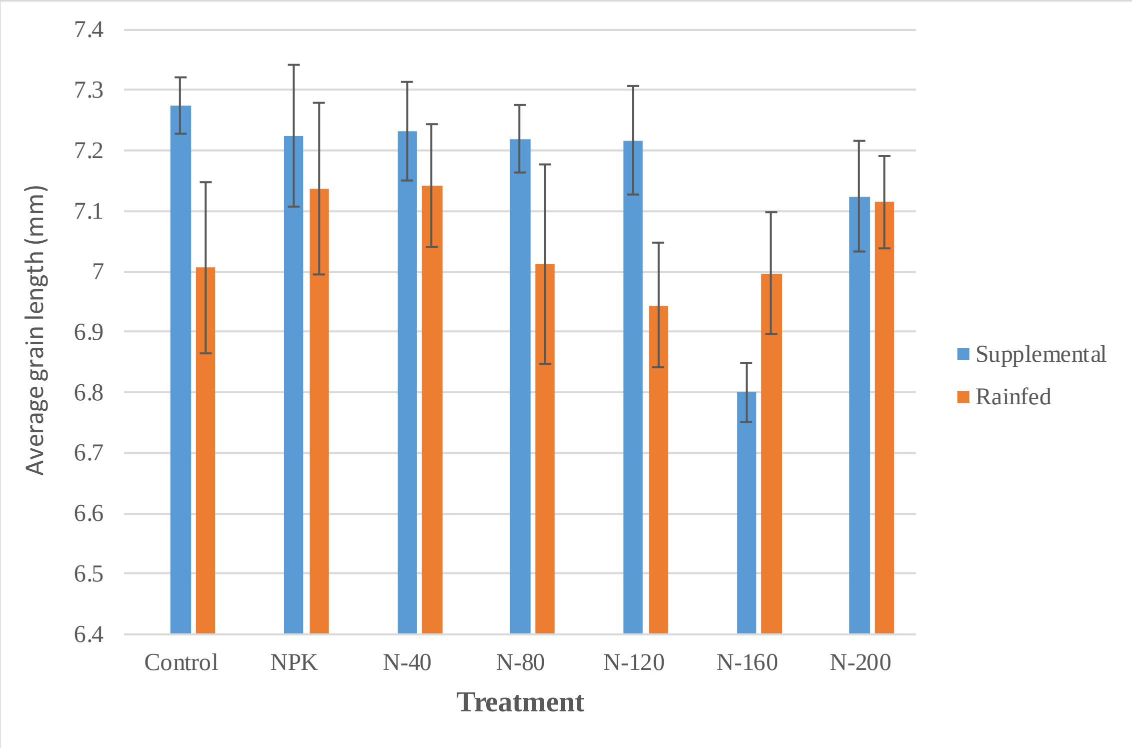
4.4.7.3 Grain length

Similar to the results of the grain parameters, supplementary irrigation with or without nitrogen (Except nitrogen at 160 kg/ha) enhanced grain length in compassion to the same treatments under rainfed conditions (Table 52 and Figure 39). Except for nitrogen at 160 kg/ha, all tested rates of nitrogen under both systems had no significant effect on grain length. The control treatment under the supplemental irrigation system is significantly higher than nitrogen at 160 kg/ha. These two treatments represent the highest and lowest average grain length under supplementary irrigation, 7.28 and 6.80 mm, respectively.

Our results showed that the highest average grain length led to the highest average grain weight and thousand grain weight under supplemental irrigation and rainfed systems (Table 53 and Table 54). Under supplemental irrigation system, control treatment recorded the highest average grain length (7.28 mm), leading to the highest average grain weight/area and thousand grain weight, 642.05 and 31.13 g, respectively. On the flipped side, the average grain length of both treatments NPK and nitrogen at 40 kg/ha under rainfed was 7.13 and 7.14 mm, respectively, leading to the highest average grain weight/area, 497.83 and 486.97g, respectively; Also, these treatments produced the highest average thousand grain weight 497.83 and 486.97g, respectively.

As a result, it is very likely to use grain length of grain as an indicator for the grain weight. Previous studies by (Alemu *et al*., 2020) indicated a significant positive relationship between durum wheat grain length and grain width in Ethiopia (Table 55).

Figure 39. *Average of grain length (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*



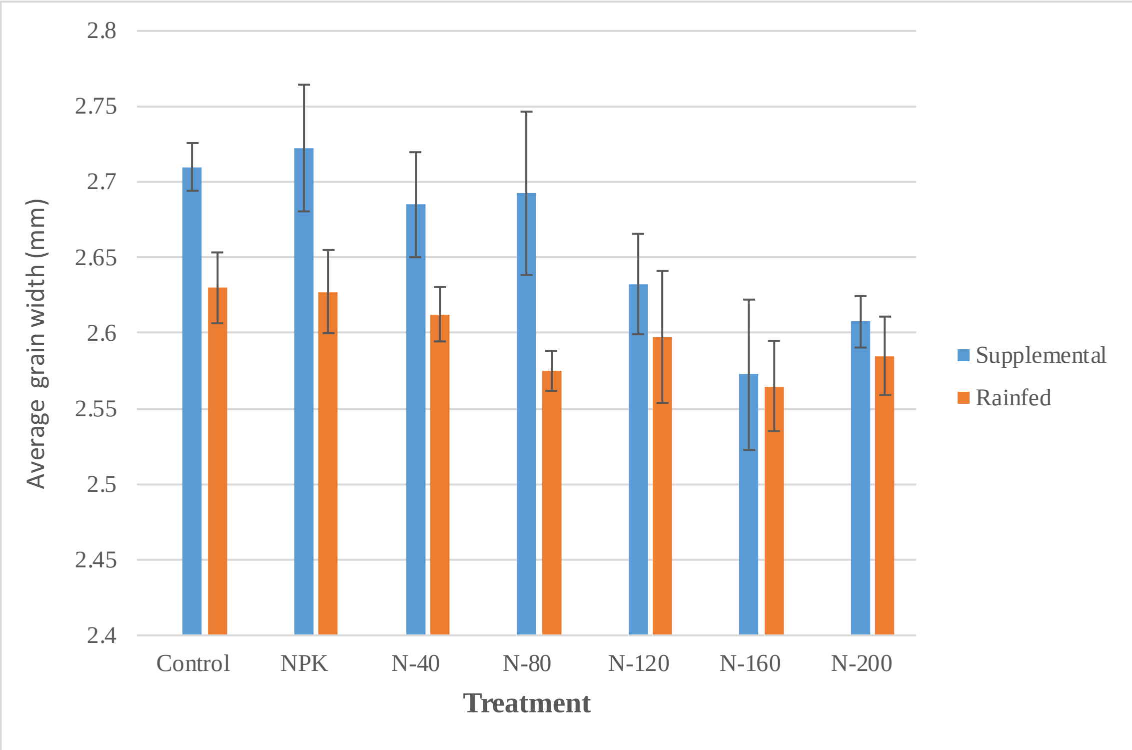
4.4.7.4 Grain width

Supplementary irrigation alone significantly increased the grain width in compassion to the rain fed condition (Table 56 and Figure 40). Addition of NPK or nitrogen at all tested rates did not significantly increase the grain width under both irrigation systems, compared to their respective controls. Both irrigation systems alone or with NPK gave the highest grain width.

Our results show the highest average grain width lead in most cases to the highest average grain weight under supplemental irrigation and rainfed systems, as presented in Table 57 and 58. Under supplemental irrigation system, the control treatment produced the highest grain weight and thousand-grain weight, 642.05 & 31.13 g, respectively. NPK treatment gave the highest grain width but did not produce the highest grain weight/area and thousand-grain weight, 635.75 and 31.05g, respectively (Figure 26 and 27). The highest average of grain weight (497.83 g) and thousand-grain weight (27.80 g) increased with NPK fertilizer under rainfed condition (Figure 26).

According to our results and to various previous studies, it is possibility to predict the production of grain weight by examining the grain width. For instance, Gegas *et al*. (2010) found a positive correlation between the grain size and shape and grain weight in wheat.

Figure 40. *Average of grain width (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=1000 seed ×4 replicates)*



4.4.7.5 Overview of impact of nitrogen fertilization and watering system on grain size

Our results show that morphological measurements of supplementary irrigation alone or with nitrogen were higher than under rainfed conditions. Previous studies indicated that grain size increased when the crops were irrigated compared to the same crops planted under rain fed conditions. Qi-hua *et al*. (2014) showed that grain length, grain area, and grain perimeter of rice were significantly improved under irrigation system. Regarding the impact of nitrogen treatments on the grain morphological traits, our results presented here show that nitrogen did not increase the average of morphological grain traits in comparison to the control under supplemental irrigation.

Addition of nitrogen at various tested rates had no significant effect on various growth parameters under supplementary irrigation. There is a possibility that the soil is already rich with nitrogen or over-fertilized and thus had no significant effect on growth parameters. Besides, the land of the experiment was planted with lentils the year before this study. This may cause an increase in the nitrogen level in the soil. Zhang *et al*. (2013) found that nitrogen had no effect on the average grain measurements and thousand-grain weight under rain fed system (Table 59).

CHAPTER 5

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary

This chapter presents the conclusion derived from this study which is to examine the effect of various rates of nitrogen fertilizers on growth parameters and yield quantity and quality of triticale under rainfed and supplementary irrigation. It also provides the recommendation that researchers and farmers can pursue.

5.2 Conclusion

It can be concluded from this study that the highest yield was obtained under supplementary irrigation alone. Supplementary irrigation alone is the most influential factor on triticale growth and yield quantity and quality compared to rainfed. Nitrogen at all tested levels have a minor effect on triticale yield under both irrigation systems. No significant differences between many of the tested nitrogen applications on yield quantity and quality of triticale. Supplementary irrigation alone could give higher biomass and yield quantity and better grain quality than other nitrogen fertilizers under rainfed conditions. The experiment proved the importance of planting legume crops prior to triticale as part of crop rotation. It showed that growing triticale after legume could save nitrogen fertilizers. This study could be a promising gate for the production of triticale in the Beqaa plain.

5.3 Recommendation

Based on these field studies it is recommended that:

- Soil analysis prior to planting triticale is required to specify the amount of nitrogen and the ratio of nutrients in the soil.
- Rotation with legumes must be considered whenever growers decided to introduce triticale in their cropping system.
- Sequential supplemental irrigation is highly recommended.
- This study should be repeated before a final recommendation to the potential triticale growers in the Beqaa plain can be made. Yet, it's recommended to add NPK at 100 kg/ha at planting under both irrigation systems.
- Further studies should be done to investigate the effect of different planting dates and varieties of triticale in order to identify the most reliable planting date and varieties in the Beqaa plain.
- Further studies should be done to investigate the effect of other nutrients on triticale growth under different locations in Lebanon and under both irrigation systems.

CHAPTER 6

APPENDIX

6.1 Tables of data results

6.1.1 Effect on plant height, fresh weight, and dry weight

Table 25. *Average of plant height (cm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 80 plants)*

	100 DAP		170 DAP		225 DAP	
Treatments	S	R	S	R	S	R
Control	22.68$^{\alpha}$ ± 1.57	22.138 ± 1.05	97.550$^{\beta}$ ± 2.65	90.563 ± 2.55	97.66$^{\beta,\Gamma}$ ± 3.72	100.125 ± 4.17
NPK	20.88$^{\alpha}$ ± 0.30	23.30$^{\alpha}$ ± 1.06	97.55$^{\beta}$ ± 5.73716	98.98$^{\beta}$ ± 2.67	99.88$^{\beta,\Gamma}$ ± 5.26	101.25$^{\beta,\Gamma}$ ± 3.14
N-40	21.08$^{\alpha}$ ± 0.68	23.89$^{\alpha}$ ± 0.63	100.18$^{\beta}$ ± 3.11866	94.95$^{\beta}$ ± 3.79	97.96$^{\beta,\Gamma}$ ± 5.56	99.26$^{\beta,\Gamma}$ ± 5.44
N-80	20.66$^{\alpha}$ ± 0.52	24.62$^{\alpha}$ ± 1.51	102.99$^{\beta}$ ± 4.815529	99.29$^{\beta}$ ± 0.69	101.03$^{\beta,\Gamma}$ ± 4.08	100.60$^{\beta,\Gamma}$ ± 3.95
N-120	21.31$^{\alpha}$ ± 0.54	24.51$^{\alpha}$ ± 0.52	104.788$^{\beta}$ ± 1.945012	96.89$^{\beta}$ ± 0.69	98.86$^{\beta,\Gamma}$ ± 3.79	101.65$^{\beta,\Gamma}$ ± 2.00
N-160	21.98$^{\alpha}$ ± 1.64	25.28$^{\alpha}$ ± 1.04	106.36$^{1\beta}$ ± 4.644682	92.19$^{2\beta}$ ± 1.72	101.96$^{\beta,\Gamma}$ ± 4.93	98.05$^{\beta,\Gamma}$ ± 3.64
N-200	21.76$^{\alpha}$ ± 0.69	24.38$^{\alpha}$ ± 0.75	105.43$^{1\beta}$ ± 2.400738	88.94$^{2\beta}$ ± 2.80	101.95$^{\beta,\Gamma}$ ± 1.99	97.14$^{\beta,\Gamma}$ ± 4.47

^{1,2} Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)
$^{\alpha,\beta,\Gamma}$ Means in a row with different Greek superscripts are significantly different ($P < 0.05$). Greek letters indicate a significant difference in date of data collection between the first data collection, second data collection, and third data collection

Table 26. *Average plant height (cm) of triticale regardless the watering system after (100 DAP) ± SE, (n=160 plants)*

Treatment	Average ± SE
Control	22.41 ± 0.88
NPK	22.10 ± 0.87
N-40	22.48 ± 0.86
N-80	22.64 ± 1.05
N-120	22.91 ± 0.70
N-160	23.63 ± 1.09
N-200	23.10 ± 0.86

Table 27. *Average of dry weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=80 plants)*

Treatments	100 DAP		170 DAP	
	S	R	S	R
Control	24.40 ± 2.66	19.10 ± 2.25	90.33 ± 11.66	88.60[a,b] ± 4.17
NPK	16.78 ± 1.72	17.36 ± 0.65	88.80[1] ± 12.88	111.28[2a] ± 7.44
N-40	18.42 ± 1.68	19.35 ± 2.73	96.55 ± 13.38	99.30[a,b] ± 12.48
N-80	17.84 ± 1.16	21.73 ± 2.61	94.10 ± 17.47	91.55[a,b] ± 10.31
N-120	18.41 ± 1.66	17.25 ± 1.66	107.45 ± 10.08	97.98[a,b] ± 2.58
N-160	17.79 ± 1.46	21.51 ± 0.49	96.38 ± 9.57	82.10[a,b] ± 2.61
N-200	17.41 ± 1.39	21.63 ± 2.43	93.78[1] ± 6.58	74.18[2b] ± 5.95

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)

[a, b] Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

Table 28. *Average of dry weight of triticale (g) regardless of the watering system at first data collection ± SE, (n=160 plants)*

Treatment	Average ± SE
Control	21.75 ± 1.90
NPK	17.10 ± 0.86
N-40	18.89 ± 1.49
N-80	19.78 ± 1.51
N-120	17.83 ± 1.11
N-160	19.65 ± 1.00
N-200	19.52 ± 1.52

Table 29. *Average of fresh weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems after (170 DAP) ± SE, (n=80 plants)*

Treatments	S	R
Control	283.05 ± 35.90	231.53 ± 16.81
NPK	279.80 ± 57.23	285.80 ± 15.20
N-40	295.88 ± 41.85	286.38 ± 37.40
N-80	282.43 ± 59.73	226.95 ± 28.53
N-120	288.55 ± 27.57	254.25 ± 14.14
N-160	281.45 ± 21.68	209.28 ± 19.16
N-200	265.68 ± 21.98	186.28 ± 23.59

6.1.2 Effect on grain weight per square meter and thousand grain weight

Table 30. *Average of grain weight (g) of triticale per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)*

Treatments	S	R
Control	642.05^{1} ± 71.69	404.08^{2} ± 39.49
NPK	635.75^{1} ± 24.47	497.83^{2} ± 21.29
N-40	635.65^{1} ± 10.90	486.97^{2} ± 22.68
N-80	598.55^{1} ± 41.63	478.85^{2} ± 10.38
N-120	534.28 ± 56.34	464.58 ± 30.50
N-160	588.17^{1} ± 41.30	466.25^{2} ± 30.29
N-200	588.40^{1} ± 30.05	418.13^{2} ± 30.99

[1,2] Means in a row with different Arabic numerical superscripts are significantly different (*P* < 0.05)

Table 31. *Average of thousand grain weight (g) of triticale under rainfed ® and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	$31.13^{1a} \pm 0.53$	$26.48^{2} \pm 1.01$
NPK	$31.05^{1a} \pm 1.42$	$27.80^{2} \pm 1.35$
N-40	$29.98^{a} \pm 0.98$	27.25 ± 0.54
N-80	$29.60^{1a,b} \pm 1.45$	$26.40^{2} \pm 0.61$
N-120	$27.78^{a,b} \pm 1.26$	26.35 ± 0.95
N-160	$25.20^{b} \pm 0.81$	25.45 ± 1.14
N-200	$27.35^{a,b} \pm 0.41$	26.25 ± 0.97

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$).
[a, b] Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$).

Table 32. *Estimating grain weight (kg) of triticale for one-dunum and one-hectare under supplemental (S) irrigation system*

Treatment	Area (1,000 m^2)	Area (10,000 m^2)
Control	642.05	6,420.50
NPK	635.75	6,357.50
N-40	635.65	6,356.50
N-80	598.55	5,985.50
N-120	534.28	5,342.80
N-160	588.17	5,881.70
N-200	588.40	5,884.00

Table 33. *Estimating grain weight (kg) of triticale for one-dunum and one-hectare under rainfed (R) conditions*

Treatment	Area (1,000 m^2)	Area (10,000 m^2)
Control	404.08	4,040.80
NPK	497.83	4,978.30
N-40	486.97	4,869.70
N-80	478.85	4,788.50
N-120	464.58	4,645.80
N-160	466.25	4,662.50
N-200	418.13	4,181.30

6.1.3 Effect on grain weight regardless of the treatments of fertilization

Table 34. *Estimating grain weight (kg) of triticale under rainfed (R) and supplemental irrigation (S) systems regardless of nitrogen fertilizer applications*

Area (m^2)	S	R
One	0.58	0.49
1000	581.63	491.43
10,000	5816.33	4914.29

6.1.4 Effect on spike weight and spike number per square meter

Table 35. *Average of spike weight (g) of triticale per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m^2)*

Treatments	S	R
Control	893.00[1] ± 95.43	641.70[2] ± 65.54
NPK	879.78 ± 35.88	767.85 ± 26.74
N-40	893.70[1] ± 14.38	740.75[2] ± 28.96
N-80	854.00 ± 56.41	767.78 ± 8.87
N-120	816.98 ± 73.78	719.93 ± 38.48
N-160	769.25 ± 54.26	739.35 ± 31.98
N-200	821.00[1] ± 39.47	656.55[2] ± 33.51

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)

Table 36. *Average of spike number of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m²)*

Treatments	S	R
Control	443.00 ± 31.14	446.25 ± 40.06
NPK	457.00 ± 32.05	491.50 ± 15.59
N-40	497.25 ± 17.38	506.25 ± 15.16
N-80	485.50 ± 36.23	526.50 ± 28.27
N-120	503.75 ± 42.77	476.00 ± 11.84
N-160	520.25 ± 30.88	520.75 ± 7.20
N-200	493.75 ± 12.02	469.25 ± 14.48

6.1.5 Effect on dry hay weight per square meter

Table 37. *Average of dry hay weight (g) of triticale stem per square meter under rainfed (R) and supplemental irrigation (S) systems ± SE, (n= 4 m²)*

Treatments	S	R
Control	670.00 ± 64.94	697.50 ± 99.78
NPK	755.00 ± 66.65	640.00 ± 108.63
N-40	795.00 ± 83.82	702.50 ± 33.26
N-80	705.00 ± 73.77	855.00 ± 100.04
N-120	805.00 ± 44.44	737.50 ± 66.88
N-160	710.00 ± 48.13	792.50 ± 56.48
N-200	830.00 ± 32.40	720.00 ± 58.02

6.1.6 Effect on grain content

6.1.6.1Effect on grain protein content

Table 38. *Average of grain protein content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R

Control	10.64[1a] ± 0.35	13.19[2] ± 0.42
NPK	10.90[a,b] ± 0.68	12.36 ± 0.59
N-40	11.49[a,b] ± 0.35	12.22 ± 0.65
N-80	11.27[1a,b] ± 0.59	13.00[2] ± 0.38
N-120	12.33[a,b] ± 0.46	13.08 ± 0.74
N-160	13.20[b] ± 0.16	12.93 ± 0.89
N-200	12.29[a,b] ± 0.36	12.30 ± 0.77

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)
[a, b] Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

6.1.6.2 Effect on grain starch content

Table 39. *Average of grain starch content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	Supplemental	Rainfed
Control	59.69[1] ± 0.24	57.21[2] ± 0.29
NPK	59.60 ± 0.55	58.23 ± 0.73
N-40	59.31 ± 0.30	58.04 ± 0.68
N-80	58.98[1] ± 0.81	57.27[2] ± 0.60
N_120	58.07 ± 0.48	57.15 ± 0.70
N-160	57.03 ± 0.39	57.07 ± 1.02
N-200	57.86 ± 0.30	57.89 ± 0.80

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)

Table 40. *Comparison between protein and starch grain content of triticale under rainfed and supplemental irrigations systems*

Treatment	S		R	
	Protein	Starch	Protein	Starch
Control	10.64	59.69	13.19	57.21
NPK	10.90	59.60	12.36	58.23
N-40	11.49	59.31	12.22	58.04
N-80	11.27	58.98	13.00	57.27
N_120	12.33	58.07	13.08	57.15
N-160	13.20	57.03	12.93	57.07
N-200	12.29	57.86	12.30	57.89

6.1.6.3 Effect on grain crude fiber content

Table 41. *Average of grain crude fiber content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	2.76 ± 0.02	2.72 ± 0.01
NPK	2.75 ± 0.01	2.78 ± 0.02
N-40	2.76 ± 0.02	2.75 ± 0.02
N-80	2.73 ± 0.01	2.71 ± 0.02
N-120	2.75 ± 0.02	2.74 ± 0.03
N-160	2.71 ± 0.01	2.75 ± 0.02
N-200	2.74 ± 0.02	1.79± 0.04

6.1.6.4 Effect on grain ash content

Table 42. *Average of grain ash content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	Supplemental	Rainfed
Control	1.54^{1a} ± 0.02	1.75^{2} ± 0.02
NPK_100 kg/ha	$1.57^{1a.b}$ ± 0.07	1.70^{2} ± 0.06
N-40	$1.63^{a,b}$ ± 0.04	1.67 ± 0.07
N-80	$1.62^{a,b}$ ± 0.08	1.74 ± 0.05
N-120	$1.71^{a,b}$ ± 0.04	1.74 ± 0.05
N-160	1.76^{b} ± 0.02	1.75 ± 0.06
N-200	$1.70^{a,b}$ ± 0.01	1.71 ± 0.03

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)

[a, b] Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

6.1.6.5 Effect on grain fat content

Table 43. *Average of grain fat content (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	Supplemental	Rainfed
Control	1.50^{1} ± 0.01	1.35^{2} ± 0.03
NPK_	1.48^{1} ± 0.02	1.41^{2} ± 0.02
N-40	1.49^{1} ± 0.01	1.41^{2} ± 0.03
N-80	1.46^{1} ± 0.03	1.39^{2} ± 0.03
N-120	1.43 ± 0.03	1.38 ± 0.04
N-160	1.39 ± 0.02	1.40 ± 0.03
N-200	1.43 ± 0.01	1.39 ± 0.02

^{1,2} Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)

6.1.6.6Effect on grain moisture content

Table 44. *Average of grain moisture (%) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

	Average moisture ratio (%) ± SE	
Treatment	Supplemental	Rainfed
Control	10.95 ± 0.09	10.88 ± 0.04
NPK	10.88 ± 0.05	10.98 ± 0.10
N-40	10.76 ± 0.18	10.97 ± 0.10
N-80	10.78 ± 0.03	10.81 ± 0.14
N-120	10.63 ± 0.07	10.90 ± 0.13
N-160	10.70 ± 0.06	10.80 ± 0.13
N-200	10.71 ± 0.04	10.95 ± 0.14

6.1.7 Effect on grain morphology

6.1.7.1 Grain area

Table 45. *Average of grain area (mm²) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	$15.52^{1a,}$ ± 0.18	14.46^{2} ± 0.34
NPK	$15.49^{a,}$ ± 0.44	14.74 ± 0.41
N-40	$15.27^{a,}$ ± 0.29	14.64 ± 0.28
N-80	$15.31^{1a,}$ ± 0.40	14.16^{2} ± 0.30
N-120	$14.9^{a,b}$ ± 0.35	14.19 ± 0.33
N-160	$13.78^{b,}$ ± 0.30	14.10 ± 0.33
N-200	$14.65^{a,b}$ ± 0.25	14.42 ± 0.31

^{1,2} Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)
^{a,b} Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

Table 46. *Average of grain area (mm²) and grain weight (g) per m² of triticale under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds) and (4 m²), respectively*

Treatments	S		R	
	Grain area (mm²)	Grain weight (g) per m²	Grain area (mm²)	Grain weight (g) per m²
Control	15.52	642.05	14.46	404.08
NPK	15.49	635.75	14.74	497.83
N-40	15.27	635.65	14.64	486.97
N-80	15.31	598.55	14.16	478.85
N-120	14.9	534.28	14.19	464.58
N-160	13.78	588.17	14.10	466.25
N-200	14.65	588.40	14.42	418.13

Table 47. *Average of grain area (mm^2) and thousand grain weight (g) of triticale, under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds)*

Treatments	S		R	
	Grain area (mm^2)	Thousand grain weight (g)	Grain area (mm^2)	Thousand grain weight (g)
Control	15.52	31.13	14.46	26.48
NPK	15.49	31.05	14.74	27.80
N-40	15.27	29.98	14.64	27.25
N-80	15.31	29.60	14.16	26.40
N-120	14.9	27.78	14.19	26.35
N-160	13.78	25.20	14.10	25.45
N-200	14.65	27.35	14.42	26.25

Table 48. *Datasets from previous experiments reporting average grain weight and grain area of wheat*

Reference	Location & season	Range in average grain area (mm^2 grain^{-1})	Range in average grain weight (mg grain^{-1})
(Wang et al., 2018)	Cultivated in Kansas in 2017	12.88−17.24	28.79−46.33
(Sanchez-Bragado *et al*., 2020)	Cultivated in Lleida, Spain in 2019	13.54−18.46	32.20−53.10
(Brinton *et al*., 2017)	Cultivated in UK in 2015 and 2016	18.04−20.61	42.73−51.27

Adapted source: (Kim *et al.*, 2021)

6.1.7.2 Grain perimeter

Table 49. *Average of grain perimeter (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	$21.59^{a} \pm 0.15$	21.05 ± 0.24
NPK	$21.58^{a} \pm 0.31$	21.27 ± 0.32
N-40	$21.52^{a} \pm 0.20$	21.26 ± 0.26
N-80	$21.52^{a} \pm 0.21$	20.94 ± 0.28
N-120	$21.42^{a,b} \pm 0.25$	20.88 ± 0.26
N-160	$20.37^{b} \pm 0.19$	20.89 ± 0.24
N-200	$21.14^{a,b} \pm 0.24$	21.14 ± 0.21

$^{a,\,b}$ Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

Table 50. *Average of grain perimeter (mm) and grain weight (g) per square meter of triticale, under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds) and (4 m^2), respectively*

Treatments	S		R	
	Grain perimeter (mm)	Grain weight (g) per m^2	Grain perimeter (mm)	Grain weight (g) per m^2
Control	21.59	642.05	21.05	404.08
NPK	21.58	635.75	21.27	497.83
N-40	21.52	635.65	21.26	486.97
N-80	21.52	598.55	20.94	478.85
N-120	21.42	534.28	20.88	464.58
N-160	20.37	588.17	20.89	466.25
N-200	21.14	588.40	21.14	418.13

Table 51. *Average of grain perimeter (mm) and thousand grain weight (g) of triticale under rainfed (R) and supplemental irrigation (S) systems, (n=4,000 seeds)*

Treatments	S		R	
	Grain perimeter (mm)	Thousand grain weight (g)	Grain perimeter (mm)	Thousand grain weight (g)
Control	21.59	31.13	21.05	26.48
NPK	21.58	31.05	21.27	27.80
N-40	21.52	29.98	21.26	27.25
N-80	21.52	29.60	20.94	26.40
N-120	21.42	27.78	20.88	26.35
N-160	20.37	25.20	20.89	25.45
N-200	21.14	27.35	21.14	26.25

6.1.7.3 Grain length

Table 52. *Average of grain length (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	$7.28^{a} \pm 0.05$	7.01 ± 0.14
NPK	$7.23^{a,b} \pm 0.18$	7.13 ± 0.14
N-40	$7.23^{a,b} \pm 0.08$	7.14 ± 0.10
N-80	$7.22^{a,b} \pm 0.06$	7.01 ± 0.17
N-120	$7.22^{a,b} \pm 0.09$	6.95 ± 0.10
N-160	$6.80^{b} \pm 0.05$	7.00 ± 0.10
N-200	$7.13^{a,b} \pm 0.09$	7.12 ± 0.08

^{a,b} Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

Table 53. *Average of grain length (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively*

Treatments	S		R	
	Grain length (mm)	Grain weight (g) per m^2	Grain length (mm)	Grain weight (g) per m^2
Control	7.28	642.05	7.01	404.08
NPK	7.23	635.75	7.13	497.83
N-40	7.23	635.65	7.14	486.97
N-80	7.22	598.55	7.01	478.85
N-120	7.22	534.28	6.95	464.58
N-160	6.80	588.17	7.00	466.25
N-200	7.13	588.40	7.12	418.13

Table 54. *Average of grain length (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively*

Treatments	S		R	
	Grain length (mm)	Thousand grain weight (g)	Grain length (mm)	Thousand grain weight (g)
Control	7.28	31.13	7.01	26.48
NPK	7.23	31.05	7.13	27.80
N-40	7.23	29.98	7.14	27.25
N-80	7.22	29.60	7.01	26.40
N-120	7.22	27.78	6.95	26.35
N-160	6.80	25.20	7.00	25.45
N-200	7.13	27.35	7.12	26.25

Table 55. *Range of kernel shape of Ethiopian durum wheat*

	Grain length (mm)	Grain width (mm)
Maximum	8.84	3.57
Median	7.83	3.09
Minimum	5.21	2.44

Adapted source: (Alemu *et al*., 2020)

6.1.7.4 Grain width

Table 56. *Average of grain width (mm) of triticale under rainfed (R) and supplemental irrigation (S) systems ± SE, (n=4,000 seeds)*

Treatments	S	R
Control	$2.71^{a,b} \pm 0.02$	2.63 ± 0.02
NPK_	$2.72^{1,a} \pm 0.04$	$2.63^{2} \pm 0.02$
N-40	$2.69^{a,b} \pm 0.03$	2.61 ± 0.02
N-80	$2.69^{1,a,b} \pm 0.05$	$2.58^{2} \pm 0.01$
N-120	$2.63^{a,b} \pm 0.03$	2.60 ± 0.04
N-160	$2.57^{b} \pm 0.05$	2.57 ± 0.03
N-200	$2.61^{a,b} \pm 0.02$	2.59 ± 0.03

[1,2] Means in a row with different Arabic numerical superscripts are significantly different ($P < 0.05$)
[a, b] Means in a column with different alphabetical superscripts are significantly different ($P < 0.05$)

Table 57. *Average of grain width (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems (n=4,000 seeds) and (4 m^2), respectively*

Treatments	S		R	
	Grain width (mm)	Grain weight (g) per m^2	Grain width (mm)	Grain weight (g) per m^2
Control	2.71	642.05	2.63	404.08
NPK	2.72	635.75	2.63	497.83
N-40	2.69	635.65	2.61	486.97
N-80	2.69	598.55	2.58	478.85
N-120	2.63	534.28	2.60	464.58
N-160	2.57	588.17	2.57	466.25
N-200	2.61	588.40	2.59	418.13

Table 58. *Average of grain width (mm) and grain weight (g) per square meter of triticale under rainfed (R) and supplemental irrigation (S) systems , (n=4,000 seeds) and (4 m²), respectively*

Treatments	S		R	
	Grain width (mm)	Thousand grain weight (g)	Grain width (mm)	Thousand grain weight (g)
Control	2.71	31.13	2.63	26.48
NPK	2.72	31.05	2.63	27.80
N-40	2.69	29.98	2.61	27.25
N-80	2.69	29.60	2.58	26.40
N-120	2.63	27.78	2.60	26.35
N-160	2.57	25.20	2.57	25.45
N-200	2.61	27.35	2.59	26.25

6.1.7.5 Overview of impact of nitrogen fertilization and watering system on grain size

Table 59. *Comparison of grain measurements and thousand grain weight under three cultivation treatments*

Cultivation treatment	Irrigation (m^3/ha)			Nitrogen fertilizer (N, kg/ha)		Grain measurements & weight		
	Overwintering stage	Jointing stage	Heading stage	Sowing stage	Jointing stage	Average grain length (mm)	Average grain width (mm)	Average *TGW (g)
Irrigated and fertilized (IF)	600	600	600	135	90	6.70	3.45	45.70
Rainfed (RF)	*NA	*NA	*NA	135	90	6.36	3.17	35.50
Reduced in nitrogen (RN)	600	600	600	135	*NA	6.37	3.33	39.40

Adapted source: (Zhang *et al*., 2013)

*NA = Not applicated, *TGW =thousand grain weigh

6.2 Syntax code of SPSS

```
* Encoding: UTF-8.
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Treatment
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  /EMMEANS=TABLES(Number_of_collecting_data*Watering_System*Treatment)
COMPARE(Number_of_collecting_data) ADJ(BONFERRONI)
  /PRINT=HOMOGENEITY  DESCRIPTIVE
  /CRITERIA=ALPHA(.05)
  /DESIGN=Number_of_collecting_data Watering_System Treatment
Number_of_collecting_data*Watering_System Watering_System*Treatment
 Number_of_collecting_data*Treatment
Number_of_collecting_data*Watering_System*Treatment

UNIANOVA  Plant_hight_cm BY Number_of_collecting_data Watering_System
Treatment
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
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  /EMMEANS=TABLES(Number_of_collecting_data*Watering_System*Treatment)
COMPARE(Watering_System) ADJ(BONFERRONI)
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  /CRITERIA=ALPHA(.05)
  /DESIGN=Number_of_collecting_data Watering_System Treatment
Number_of_collecting_data*Watering_System Watering_System*Treatment
 Number_of_collecting_data*Treatment
Number_of_collecting_data*Watering_System*Treatment

UNIANOVA  Plant_hight_cm BY Number_of_collecting_data Watering_System
Treatment
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  /INTERCEPT=INCLUDE
  /PLOT=PROFILE(Number_of_collecting_data*Watering_System*Treatment)
  /EMMEANS=TABLES(Number_of_collecting_data*Watering_System*Treatment)
COMPARE(Treatment) ADJ(BONFERRONI)
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  /CRITERIA=ALPHA(.05)
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 Number_of_collecting_data*Treatment
Number_of_collecting_data*Watering_System*Treatment
```

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