

## Article

# Durum Wheat Yield and Grain Quality in Early Transition from Conventional to Conservation Tillage in Semi-Arid Mediterranean Conditions

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**Abstract:** In semi-arid Mediterranean areas, there is a growing interest in adopting conservation tillage practices for their advantages in improving soils fertility, reducing production costs, and stabilizing crop yields. The aim of this study conducted in the 2019 and 2020 seasons was to investigate the effect of three tillage systems—conventional tillage (CT), minimum tillage (MT), and no-tillage (NT)—on grain yield, yield components, and quality indices of a durum wheat crop (*Triticum durum* Desf. cv. Simeto) grown in monoculture in semi-arid conditions of Northern Algeria. Tillage systems had a significant effect on the average yield of the 2 years, with NT being 28% and 35% higher than CT and MT, respectively—a trend even more evident in the second year under observation. The superiority of NT ( $p < 0.001$ ) in the second year (2020) is mainly due to the increased spikes density (318.93 spikes m<sup>2</sup> under NT vs. 225.07 and 215.20 spikes m<sup>2</sup> under MT and CT, respectively). Yield components and quality parameters were more affected by climatic conditions than by tillage treatments. The number of kernels per spike being the most affected by water and heat stresses occurred in 2020 season. A decrease of 51% is noted regardless of the tillage treatment, which negatively affected the grain yield in that year (1.9 vs. 1.3 t ha<sup>−1</sup> in 2019 and 2020, respectively). This stress also induced an increase in grain protein content, but a reduction of its weight. The results of this study conducted in the early transition from conventional to conservation tillage show that durum wheat grown under NT results in higher grain yield than the other systems in the specific operative conditions of the study region, providing better seed emergence and better spikes density, especially in the dry years. Moreover, the quality parameters are more affected by weather conditions than by the tillage system—with an interaction year × tillage system significant only for the grain.

**Keywords:** conservation tillage; durum wheat; grain yield; grain quality; semi-arid conditions

## 1. Introduction

Durum wheat (*Triticum durum* Desf.) is a strategic crop in the Mediterranean region, especially in Algeria where the area occupied by this crop is about 2 M ha with an annual production of 2 M t. Cereal production is concentrated in the interior high plains characterized by a Mediterranean climate with variable rainfall and frequent droughts, soils with low organic matter levels, and low water retention capacity. These conditions have considerably limited the choice of crops in this area [1]. Consequently, the cropping

systems adopted in the region are based on cereal monoculture, fallow, and deep and intensive tillage. These practices, which are mainly designed for water storage, have shown their limitation, leading to soil loss through water and wind erosion and a decline in soil fertility [2,3]. Under these conditions, the adoption of conservation agriculture, based on minimizing soil disturbance, maximizing plant residue coverage, and diversifying crops seems to be more sustainable.

Despite the introduction in Algeria in the late 1990s [4], the spread of conservation agriculture in the country remains modest and has only reached 5600 ha by 2016 [5], which may be due to the lack of information among farmers about this system. No serious research on the effect of conservation agriculture, particularly, conservation tillage has been done in the local conditions. However, numerous experiments under similar Mediterranean conditions have shown many advantages: Reduction of production costs, mainly the reduction of energy used for tillage [6–8]; improvement of water storage in the soil by reducing its evaporation and increasing its infiltration [9,10]; and preservation of soil from erosion by improving its structure with an increase of organic matter levels [11–15].

The effect of conservation agriculture on durum wheat yielding has, particularly, been deeply studied in the Mediterranean region [9,16–23]. These studies reported contradictory results according to the variable climatic conditions. The variability of these results proves that the influence of different tillage systems on crop performance is highly dependent on weather conditions—with NT inducing better yields in dry years—while in wet conditions the CT gives higher durum wheat. On the other hand, the effect of tillage systems on grain quality has been less investigated in the region. Nowadays, semolina mills have high requirements for durum wheat grain quality, protein content  $> 12.5\%$ , test weight  $> 80 \text{ kg hL}^{-1}$ , and a vitreosity percentage  $> 75\%$  [9,24] are highly appreciated. The protein content is the most important quality trait in semolina used for pasta making, which is closely dependent on nitrogen availability, climatic conditions, and genotype [25]. However, tillage systems seem to also affect this parameter. Studies conducted under the same conditions in southern Italy report higher protein concentration by CT in wet conditions [21], while in dry years durum wheat grown under the NT system resulted in higher protein levels [9,26]. This climate-tillage interaction effect on protein content, is mainly due to the higher water storage of NT in dry conditions and its lower nitrogen availability in wet conditions, compared to CT. The vitreous aspect of durum wheat grain is also an important quality trait, as a high percentage of vitreous kernels increases the semolina yield of a uniform particle size and reduces the amount of unwanted flour [24]. The grain vitreosity and protein concentration are highly correlated. Therefore, a reduction of grain protein concentration may negatively affect its vitreous aspect. In a study by [27], a decrease in protein content in NT resulted in a significantly lower percentage of vitreous grains compared to CT. Thousand kernels weight and test weight are significantly reduced in the dry conditions [28], thus NT gives better grain weight compared to CT in drought conditions due to the high water retention [9,16] and better roots development under NT [29]. However, in the wettest years, a similar grain weight was found in the different tillage systems by [21] and [30].

Most of the cited research work has been conducted in long-term experiments. However, few studies have investigated the short-term effect of tillage systems on grain yield and the quality of durum wheat under Mediterranean conditions. Accordingly, the aim of the present study is to investigate the short-term effect of three tillage systems—no tillage (NT), minimum tillage (MT), and conventional tillage (CT)—on the yield and grain quality of durum wheat under rain-fed conditions in a semi-arid region of Northern Algeria.

## 2. Materials and Methods

### 2.1. Experimental Site

The study was carried out in an ongoing trial that started in 2015 in a farm located in the region of El Hachima (Bouira) situated in the North of Algeria ( $36^{\circ}14'21'' \text{ N}$ ,  $3^{\circ}50'23'' \text{ E}$  at an altitude of 713 m). The climate is Mediterranean characterized by a great variation

of rainfall. Meteorological data over 30 years (1990–2020) show that the average annual rainfall in the region is 479 mm, 70% of which was recorded during the period from November to April. The monthly average minimum temperature over this period was 4 °C recorded in January and February and the monthly average maximum temperature was recorded in July with 35 °C, the average temperature for the year being 17 °C. The weather parameters were recorded by the meteorological station of Ain Bessam of the Algerian national office of meteorology, the station is located 1 km from the experimental site. The soil has a clay texture composed of 54% clay, 28% silt, and 16% sand. Its characteristics before the experiment are presented in Table 1.

**Table 1.** Soil characteristics before the experiment setup (0–30 cm).

| Soil Parameters                   | Value | Method                  |
|-----------------------------------|-------|-------------------------|
| pH                                | 7.7   | pH meter [31]           |
| Limestone rate %                  | 4.0   | [32]                    |
| Organic C (C%)                    | 1.1   | Anne method [33]        |
| Conductivity (mS/cm)              | 0.15  | Conductivity meter [34] |
| Available P (ppm)                 | 30.0  | Olsen method [35]       |
| Exchangeable K <sup>+</sup> (ppm) | 452.0 | Mehlich III [36]        |

## 2.2. Climatic Conditions

Climatic conditions for the 2 years of the study compared with the 30-year data (1990–2020) in the region are shown in Table 2. There was an important variation in rainfall between the 2 years, which is typical of the Mediterranean climate. The rainfall obtained during the crop cycle (December–June) in the 2018–2019 season followed the long-term data (321 and 331 mm, respectively), while the 2019–2020 season recorded a decrease of about 25% (249 mm). The cumulative rainfall obtained during the vegetative period (from sowing to heading) from December to March in the first year (248 mm) was 42% higher than that obtained during the same period in the second year (144 mm). However, the reproductive period (heading to maturity) from the end of March to June was drier in the first year of the study (73 mm) with a 30% decrease compared to the second year and the long-term data both corresponding to 105 mm.

**Table 2.** Monthly rainfall and mean maximum and minimum temperature for the 2 years of the study (2019–2020) compared to the long-term data (1990–2020) recorded in the study area.

| Months | 2018–2019         |             |                       |                       | 2019–2020         |             |                       |                       | 1990–2020         |             |                       |                       |
|--------|-------------------|-------------|-----------------------|-----------------------|-------------------|-------------|-----------------------|-----------------------|-------------------|-------------|-----------------------|-----------------------|
|        | Sum Rainfall (mm) | Mean T (°C) | T <sub>min</sub> (°C) | T <sub>max</sub> (°C) | Sum Rainfall (mm) | Mean T (°C) | T <sub>min</sub> (°C) | T <sub>max</sub> (°C) | Sum Rainfall (mm) | Mean T (°C) | T <sub>min</sub> (°C) | T <sub>max</sub> (°C) |
| Nov.   | 84                | 12          | 8                     | 16                    | 97                | 12          | 8                     | 15                    | 57                | 13          | 8                     | 17                    |
| Dec.   | 66                | 11          | 6                     | 16                    | 37                | 11          | 7                     | 15                    | 57                | 9           | 5                     | 13                    |
| Jan.   | 121               | 7           | 3                     | 11                    | 37                | 9           | 5                     | 13                    | 68                | 8           | 4                     | 12                    |
| Feb.   | 20                | 9           | 4                     | 14                    | 0                 | 13          | 6                     | 19                    | 50                | 9           | 4                     | 13                    |
| March  | 41                | 12          | 6                     | 17                    | 70                | 13          | 8                     | 17                    | 51                | 12          | 6                     | 17                    |
| Apr.   | 32                | 14          | 8                     | 19                    | 69                | 15          | 10                    | 20                    | 50                | 14          | 8                     | 19                    |
| Mai    | 26                | 17          | 11                    | 23                    | 30                | 21          | 14                    | 28                    | 41                | 18          | 12                    | 24                    |
| June   | 15                | 26          | 18                    | 34                    | 6                 | 24          | 16                    | 31                    | 14                | 23          | 16                    | 30                    |
| Means  | 405 *             | 13          | 8                     | 19                    | 346 *             | 15          | 9                     | 20                    | 388 *             | 13          | 8                     | 18                    |

\* Total rainfall.

Temperatures also followed the long-term data during the first year. However, in the second year, the average minimum temperatures recorded an increase of 2 °C throughout the crop cycle compared to the 30-year data and the maximum temperatures recorded increases of 6 and 4 °C compared to the long-term data during February and May, respectively.

### 2.3. Experimental Design and Crop Management

The study was carried out during the two growing seasons, in 2018–2019 and 2019–2020, named in the next parts of the paper as 2019 and 2020, respectively. Three tillage systems were compared: Conventional tillage (CT) consisting of moldboard plowing to 25 cm depth, followed by disking and harrowing for seedbed preparation, minimum tillage (MT) performed by a shallow “ducks foot” cultivator to 7 cm depth followed by harrowing for seedbed performance, and no-tillage (NT), where the durum wheat crop was sown directly with a direct seed drill without any tillage operation. The experimental design was a randomized complete block with three replications (blocks), with each block containing three experimental units (plots) holding the studied tillage treatments. The plots of 600 m<sup>2</sup> (60 × 10 m) were separated by 2 m, while the blocks were separated by 7 m. The preceding crop in the previous 3 years was durum wheat managed in the same tillage practice in each plot since 2015. Crop residues of the previous season’s harvest chopped by the combine harvester at a height of 30 cm were incorporated in-depth with the soil plowing for CT. They were cut and distributed homogeneously over the plot for MT, while, finally, they were retained straight above the ground for NT.

Durum wheat was sown in 10 December 2018 and 18 December 2019 during the first and the second growing seasons, respectively. The sowing operation was carried out late compared to the dates adapted to the region (mid-November) due to the wet conditions during November in the 2 years, as well as due to the clay texture of the soil in the experimental site, which have interfered with the access of the engines carrying out the soil preparation and sowing operations. Simeto cultivar, the most cultivated in the region, was used for this study, and the sowing rate was set to have 350 viable seeds m<sup>-2</sup> depending on the characteristics of the seeds used in each year. NT plots were weeded with glyphosate (2.5 L ha<sup>-1</sup>) every year just before sowing. Fertilization at the rate of 150 kg ha<sup>-1</sup> as mono-ammonium phosphate (12% N, 52% P, and 0% K) was applied each year in all the plots at the time of sowing and 100 kg ha<sup>-1</sup> of urea (46% N) was added at the early tillering stage of the crop. As early as weeds appear, a specific weed control based on Clodinafop-propargyl (1 L ha<sup>-1</sup>) and Tribuneron-methyl (12 g ha<sup>-1</sup>) was applied at the young stages of the crop. Insect pests such as aphids, beetles and leafrollers, as well as fungal diseases such as brown and yellow rust, Septoria, and fusarium were sanitary threats that show up throughout the durum wheat crop cycle. For this reason, a control was ensured by an application of Lambda-cyhalothrin (250 mL ha<sup>-1</sup>) + Thiamethoxam (20 g ha<sup>-1</sup>) as insecticides and Picoxystrobin + Cyproconazole (0.5 L ha<sup>-1</sup>) as fungicide at the beginning of the first spots or symptoms.

### 2.4. Measurements and Analysis

The harvest was mechanically done for each plot and the grain yield was determined and then adjusted to 13% moisture content. Each year, before harvest, three samples of two linear meters were cut above ground level from each plot along a diagonal path for the measurement of dry biomass yield (above ground biomass), harvest index, yield components, and quality traits. The dry biomass yield was determined after passing through an oven at 75° for 48 h as the average weight of the three samples expressed in tons per hectare. The harvest index was then determined as the ratio of the grain yield to the total biomass yield. The number of spikes per square meter was obtained by counting the number of spikes in each sample. Then, the average was transformed to the surface unit. The number of kernels per spike was calculated by dividing the total weight of the kernels obtained in each sample by its corresponding number of spikes and individual kernel weight. The thousand kernel weight was calculated as the mean weight of three samples of 1000 kernels taken from the grain harvested from each plot. The test weight was determined on three 250 mL grain samples and expressed in kg hL<sup>-1</sup>. The vitreous aspect of the grains was determined on three samples of 100 kernels using a Pohl farinator and expressed as a percentage. The concentration of N in the grain is determined by the

Kjeldahl method, and the protein content is calculated by multiplying the concentration by 5.7 and expressed in  $\text{g kg}^{-1}$  dry matter [9].

### 2.5. Statistical Analysis

To compare the effect that tillage systems (TS) and the year have on the durum wheat crop, the data were subjected to analysis of variance (ANOVA), considering the TS and year as the main factors and the block as a random factor. The Fisher's least significant difference (LSD) test is used to compare the means when ANOVA shows a significant effect. The principal components analysis (PCA) was also performed using STATISTICA 6.0. [37] in order to further understand the nature and the degree of variability between the different parameters studied with respect to tillage systems during the 2 years of the experimentation.

## 3. Results

### 3.1. Effect of Tillage Systems on Yield, Yield Components, and Grain Quality

Tillage systems affected yield and yield components differently, according to the year of cultivation. Yet, they had no significant effect on the average of the 2 years for all the measured parameters except for the grain yield, with NT being 28% and 35% higher than CT and MT, respectively (Table 3). In the first year of the study (2019), the grain yield and its components, as well as the biomass yield resulted in being similar in all the tillage treatments. On the contrary, the harvest index was significantly higher under the NT system due to the late leaves senescence due to the higher water retention under this system (Tables 3 and 4). However, in the second year (2020), the effect of tillage was significant on grain ( $p < 0.001$ ) and biomass ( $p < 0.01$ ) yields. NT increased the grain yield by 32% and 48% and the biomass yield by 29% and 32% compared to conventional and minimum tillage, respectively (Tables 3 and 4). However, the yield components were less affected by tillage in the same year (2020). The spike's density is the only affected parameter, being significantly higher under NT (318.93 spikes per square meter) than MT and CT (225.07 and 215.20 spikes per square meter, respectively), which is mainly due to the better seed emergence conditions and water availability under undisturbed soil (Table 3).

**Table 3.** Influence of soil tillage systems on grain yield and its components, during the 2019 and 2020 growing seasons ( $p < 0.05$ ).

| Year (Y)                                             | Tillage Systems (TS) |                     |                     | Mean              |
|------------------------------------------------------|----------------------|---------------------|---------------------|-------------------|
|                                                      | NT                   | MT                  | CT                  |                   |
| Grain yield (t ha <sup>-1</sup> )                    |                      |                     |                     |                   |
| 2019                                                 | 2.28                 | 1.70                | 1.73                | 1.90 <sup>A</sup> |
| 2020                                                 | 1.72 <sup>a</sup>    | 0.90 <sup>b</sup>   | 1.16 <sup>b</sup>   | 1.26 <sup>B</sup> |
| Mean                                                 | 2.00 <sup>a</sup>    | 1.30 <sup>b</sup>   | 1.45 <sup>b</sup>   |                   |
| LSD <sub>0.05</sub> Y = 0.29, TS = 0.42, Y × TS = ns |                      |                     |                     |                   |
| Number of spikes per square meter                    |                      |                     |                     |                   |
| 2019                                                 | 243.47               | 229.19              | 237.35              | 236.67            |
| 2020                                                 | 318.93 <sup>a</sup>  | 225.07 <sup>b</sup> | 215.20 <sup>b</sup> | 253.07            |
| Mean                                                 | 281.20               | 227.13              | 226.28              |                   |
| LSD <sub>0.05</sub> Y = ns, TS = ns, Y × TS = 50     |                      |                     |                     |                   |

**Table 3.** *Cont.*

| Year (Y)                                           | Tillage Systems (TS) |       |       | Mean               |
|----------------------------------------------------|----------------------|-------|-------|--------------------|
|                                                    | NT                   | MT    | CT    |                    |
| Number of kernels per spike                        |                      |       |       |                    |
| 2019                                               | 37.26                | 44.07 | 40.07 | 40.46 <sup>A</sup> |
| 2020                                               | 18.36                | 19.34 | 22.63 | 20.11 <sup>B</sup> |
| Mean                                               | 27.81                | 31.71 | 31.35 |                    |
| LSD <sub>0.05</sub> Y = 3.63, TS = ns, Y × TS = ns |                      |       |       |                    |

Ns: Not significant at  $p < 0.05$ ; values followed by the same letter are statistically not different, letters in capital refer to year effect, while the lowercase letters refer to tillage effect.

**Table 4.** Influence of soil tillage systems on biomass yield and harvest index during the 2019 and 2020 growing seasons ( $p < 0.05$ ).

| Year (Y)                                             | Tillage Systems (TS) |                   |                   | Mean              |
|------------------------------------------------------|----------------------|-------------------|-------------------|-------------------|
|                                                      | NT                   | MT                | CT                |                   |
| Biomass yield (t ha <sup>-1</sup> )                  |                      |                   |                   |                   |
| 2019                                                 | 5.43                 | 7.50              | 7.55              | 6.83 <sup>A</sup> |
| 2020                                                 | 6.91 <sup>a</sup>    | 4.71 <sup>b</sup> | 4.92 <sup>b</sup> | 5.51 <sup>B</sup> |
| Mean                                                 | 6.12                 | 6.10              | 6.24              |                   |
| LSD <sub>0.05</sub> Y = 0.96, TS = ns, Y × TS = 1.67 |                      |                   |                   |                   |
| Harvest Index                                        |                      |                   |                   |                   |
| 2019                                                 | 0.43 <sup>a</sup>    | 0.23 <sup>b</sup> | 0.23 <sup>b</sup> | 0.30 <sup>A</sup> |
| 2020                                                 | 0.25                 | 0.19              | 0.24              | 0.23 <sup>B</sup> |
| Mean                                                 | 0.34                 | 0.21              | 0.23              |                   |
| LSD <sub>0.05</sub> Y = 0.04, TS = ns, Y × TS = 0.08 |                      |                   |                   |                   |

Ns: Not significant at  $p < 0.05$ ; values followed by the same letter are statistically not different, letters in capital refer to year effect, while the lowercase letters to tillage effect.

On the other hand, grain quality parameters were not significantly affected by the tillage systems investigated in the average of the 2 years (Table 5). However, the grain vitreosity was significantly increased by the conservation tillage systems (NT and MT) compared to CT in the wet year (2019), which is due to quick nitrogen leaching in the tilled soils due to the great amount of rainfall that occurred in the beginning of the season. While, in the driest year (2020), the percentage of vitreous grains was significantly reduced by NT compared to MT and CT due to the lower organic matter decomposition and nitrogen availability under the NT system (Table 5).

**Table 5.** Influence of soil tillage systems on the quality parameters during the 2019 and 2020 growing seasons ( $p < 0.05$ ).

| Year (Y)                                           | Tillage Systems (TS) |       |       | Mean               |
|----------------------------------------------------|----------------------|-------|-------|--------------------|
|                                                    | NT                   | MT    | CT    |                    |
| Test weight (kg hL <sup>-1</sup> )                 |                      |       |       |                    |
| 2019                                               | 83.67                | 83.58 | 83.35 | 83.53 <sup>A</sup> |
| 2020                                               | 77.55                | 77.55 | 77.83 | 77.64 <sup>B</sup> |
| Mean                                               | 80.61                | 80.57 | 80.59 |                    |
| LSD <sub>0.05</sub> Y = 1.18, TS = ns, Y × TS = ns |                      |       |       |                    |

Table 5. Cont.

| Year (Y)                                             | Tillage Systems (TS) |                    |                    | Mean               |
|------------------------------------------------------|----------------------|--------------------|--------------------|--------------------|
|                                                      | NT                   | MT                 | CT                 |                    |
| Thousand kernels weight (g)                          |                      |                    |                    |                    |
| 2019                                                 | 45.29                | 44.39              | 42.01              | 43.90 <sup>A</sup> |
| 2020                                                 | 39.44                | 39.39              | 38.30              | 39.04 <sup>B</sup> |
| Mean                                                 | 42.37                | 41.89              | 40.16              |                    |
| LSD <sub>0.05</sub> Y = 3.10, TS = ns, Y × TS = ns   |                      |                    |                    |                    |
| Protein content (%)                                  |                      |                    |                    |                    |
| 2019                                                 | 11.24                | 12.37              | 11.50              | 11.70 <sup>B</sup> |
| 2020                                                 | 14.27                | 13.29              | 14.06              | 13.88 <sup>A</sup> |
| Mean                                                 | 12.76                | 12.83              | 12.79              |                    |
| LSD <sub>0.05</sub> Y = 0.97, TS = ns, Y × TS = ns   |                      |                    |                    |                    |
| Grain vitreosity (%)                                 |                      |                    |                    |                    |
| 2019                                                 | 96.50 <sup>a</sup>   | 95.67 <sup>a</sup> | 83.83 <sup>b</sup> | 92.00 <sup>B</sup> |
| 2020                                                 | 94.66 <sup>b</sup>   | 97.22 <sup>a</sup> | 97.83 <sup>a</sup> | 96.57 <sup>A</sup> |
| Mean                                                 | 95.58                | 96.44              | 90.83              |                    |
| LSD <sub>0.05</sub> Y = 2.24, TS = ns, Y × TS = 3.88 |                      |                    |                    |                    |

NS: Not significant at  $p < 0.05$ ; values followed by the same letter are statistically not different, letters in capital refer to year effect, while the lowercase letters to tillage effect.

### 3.2. Effect of the Year on Yield, Yield Components, and Grain Quality

The effect of the year is significant for all the parameters under investigation except for the number of spikes per square meter (Tables 3–5). The average yield obtained during the first year of the trial ( $1.9 \text{ t ha}^{-1}$ ) is significantly higher than that of the subsequent year ( $1.3 \text{ t ha}^{-1}$ ) (Table 3). However, the number of spikes per square meter did not vary significantly between the years despite the variability of rainfall recorded during the vegetative period of the crop. The decrease in yield in the second year (2020) is mainly due to a decrease in spike fertility and the thousand kernel weight. The number of kernels per spike decreased by half (40.46 kernels per spike in 2019 vs. 20.10 kernels per spike in 2020) (Table 3), and the thousand kernel weight decreased from 43.89 g in 2019 to 39.04 g in 2020 (Table 5). Quality traits were significantly affected by the year. The protein content was higher in the dry year (11.7% in 2019 vs. 13.9% in 2020), while the test weight was significantly higher in the wet year ( $83.5 \text{ kg hL}^{-1}$  in 2019) compared to the driest one ( $77.6 \text{ kg hL}^{-1}$  in 2020). The grain vitreosity was affected by the reduction of protein content in the second year, resulting in significantly lower levels in 2020 compared to the 2019 season (96.6% vs. 92.0% in 2019 and 2020, respectively) (Table 5).

### 3.3. Effect of the Interaction Year × Tillage System on Yield, Yield Components, and Grain Quality

The interaction was significant for the biomass yield, the harvest index, the number of spikes per square meter, and the vitreous aspect of the grain. NT produced a biomass yield significantly higher in the driest year (2020) ( $5.4$  vs.  $6.9 \text{ t ha}^{-1}$  in 2019 and 2020, respectively) with a lower harvest index (0.25 in 2020 vs. 0.43 in 2019). This shows that the biomass produced has not been transformed into grain yield due to the heat stress in the period of grain filling stage, while the two other systems produced about 35% higher dry biomass in the wet year (2019) compared to the driest one (2020) with no significant variation in the harvest index. CT and MT produced the same number of spikes per square meter in both years, while NT resulted in 24% higher spike density in the second year (2020). The better sowing conditions in that year (lower soil moisture) and the good water storage capacity



under the NT system allowed a good plant emergence and better biomass production despite the recorded water shortage. The vitreous aspect of the grain significantly varied in the CT system (14% lower in 2019 than in 2020), which may be due to nitrogen leaching due to the heavy rains recorded in the vegetative period of 2019 season. However, in the conservation tillage systems, this parameter was similar in the 2 years.

### 3.4. Principal Components Analysis (PCA)

The principal components analysis is performed to get more detail on the degree of variability between the different parameters studied with respect to the tillage techniques during the 2 years of the experimentation. Here, the PCA revealed that 76% of the total variability is expressed by the two axes 1 and 2, which is why the interpretation is limited to only these two components.

Axis 1 is positively correlated with TW, TKW, NKS, and GY, and negatively correlated with grain protein content (PC), thus providing 56.5% of the variability. Axis 2 describes 19.5% of the variability and is correlated positively with total biomass yield (BY), while it is negatively correlated with harvest index (HI) and grain vitreosity (VI) (Table 6, Figure 1). The opposition of the variable PC to grain yield and its components on axis 1 shows that the grain weight is negatively correlated to PC, which indicates that, when the yield increases, PC decreases due to the nitrogen dilution in the grain.

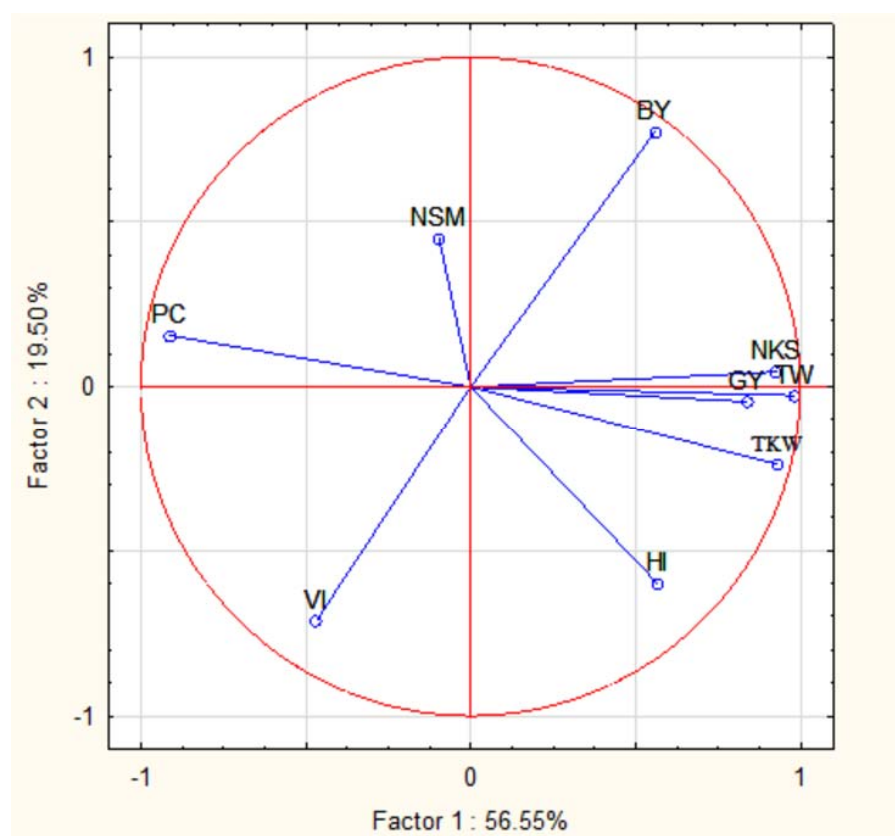
**Table 6.** Principal components analysis (PCA) based on yield, yield components, and quality parameters of durum wheat crop grown under three tillage practices in the 2019 and 2020 growing seasons.

| Parameter             | Factor 1 | Factor 2 |
|-----------------------|----------|----------|
| Eigen values          | 5.089    | 1.755    |
| % total variance      | 56.55    | 19.50    |
| Cumulative%           | 56.55    | 76.05    |
| Variable correlations |          |          |
| GY                    | 0.837    | −0.045   |
| BY                    | 0.560    | 0.774    |
| HI                    | 0.566    | −0.600   |
| NSM                   | −0.096   | 0.451    |
| NKS                   | 0.927    | 0.045    |
| TW                    | 0.983    | −0.026   |
| TKW                   | 0.982    | −0.238   |
| PC                    | −0.913   | 0.156    |
| VI                    | −0.468   | −0.712   |

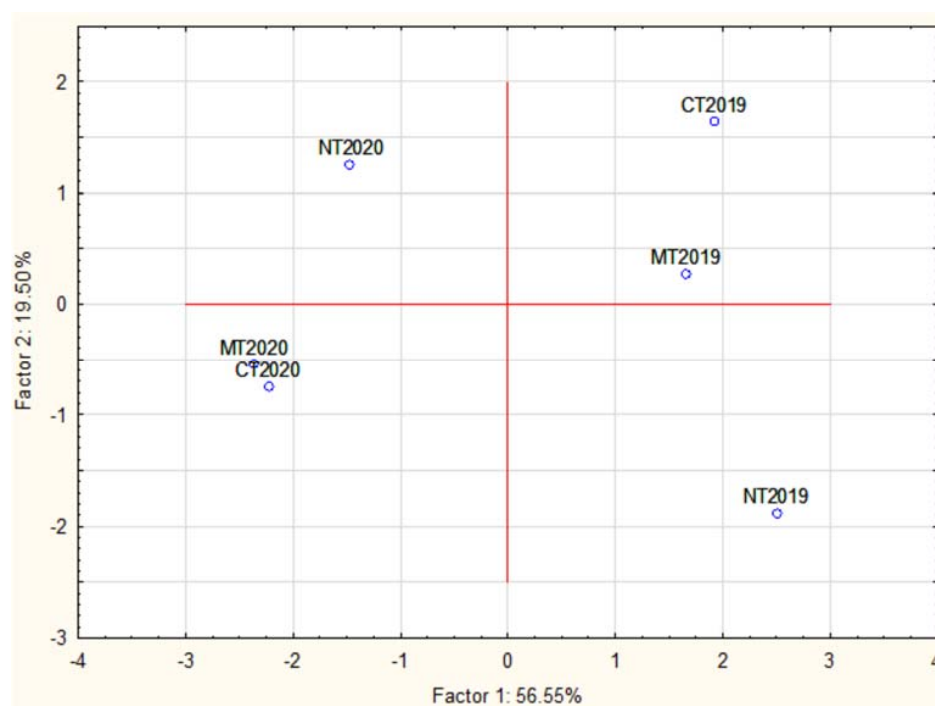
GY: Grain yield; BY: Biomass yield; HI: Harvest index; NSM: Number of spikes per square meter; NKS: Number of kernels per spike; TW: Test weight; TKW: Thousand kernel weight; PC: Protein content; VI: Grain vitreosity.

The projection of the tillage systems (TS) on the 1–2 plan (Figure 2) shows a clear opposition between the year 2019, characterized by a higher and better distributed rainfall, and the year 2020, which has been more disadvantageous in terms of climate. The tillage systems seem to have a strong influence on the variables studied albeit in different ways. In MT and CT, the crop shows a similar behavior in the two seasons. Yet, in NT, a high harvest index is recorded in the wet year (2019), thus showing a good dry matter conversion to the grain due to the delayed leaf senescence as a result of better water storage under this system. Instead, in the dry year (2020), a higher biomass production under NT was associated with a lower harvest index. This is due to more water scarcity, higher temperatures, and higher water evaporation in the period of grain filling stage in that year, which resulted in limiting dry biomass transportation to the grain.





**Figure 1.** Projection of the variables on the factor plan (1–2). Please note: GY: Grain yield; BY: Biomass yield; HI: Harvest index; NSM: Number of spikes per square meter; NKS: Number of kernels per spike; TW: Test weight; TKW: Thousand kernel weight; PC: Protein content; VI: Grain vitreosity.



**Figure 2.** Projection of the tillage systems on the factor plan (1–2). Please note: NT: No-tillage; MT: Minimum tillage; CT: Conventional tillage. The number following the tillage system refers to the year of cultivation.

#### 4. Discussion

The results obtained in this study show that there is a great variability in the parameters studied between the 2 years of the experimentation. In Mediterranean conditions, the inter-annual variability of yields is mainly related to the variability of rainfall distribution [20,21,30,38]. However, the decrease in yield observed in the second year of this study is due to a decrease in spike fertility and thousand kernel weight caused by an increase in temperature during flowering and early grain-filling stages. The daily maximum temperatures in the first week of May 2020, which coincide with the stated growing stages of the crop, ranged from 24 to 34 °C compared to 14 to 27 °C during the same period in 2019. According to [39], a temperature higher than 31 °C at the time of flowering and the beginning of grain filling can decrease the yield by 0.37 t ha<sup>-1</sup> and the thousand kernel weight by 11.7 mg. Similar results were obtained by [21], who reported a decrease in yield caused by an increase in temperature in May under similar conditions in Southern Italy.

The quality of durum wheat and other *Triticum* genotypes is highly dependent on the variable climatic conditions [40]. The protein content is negatively correlated with the grain's weight [22], which is confirmed by the results obtained in this study. In the first year (2019), the protein content (PC) was lower than the standard value required in the markets (PC > 12.5%), while the test weight (TW) meets the standards (TW > 80 kg hL<sup>-1</sup>). In the second year, an increase in the grain protein content (13.9%) was associated with a decrease in the test weight (77.6 kg hL<sup>-1</sup>). These results are in agreement with those of [39,41–43], who note that heat stress at the grain filling stage significantly increases the protein content in the grain. In [39], an increase in temperature of 5.5 °C leads to an increase of 1.3% in the grain protein content. The amount of rainfall that occurred in the vegetative period may also affect the protein concentration in the durum wheat grain. According to [21], an amount of rainfall of 250 mm at the beginning of the growing season (248 mm in the first year of our study) may lead to leaching the mineral nitrogen of the soil in that period, which may cause a deficiency of this element in the grain filling stage and, consequently, a reduction of the grain protein content. Similar observations were also reported by [22,28,44], all showing a decrease in grain protein concentration due to rainy winters.

The compared tillage systems did not have a significant effect on durum wheat productivity in the first year of this study. On the contrary, in the second year, NT gave significantly better grain and dry biomass yields due to better water storage under undisturbed and covered soil. These results are in concert with most studies conducted in semi-arid conditions, which state that CT positively affects yield in wet years, whereas in drier ones NT and MT give better yields [9,16,19,21,30,38,45,46]. Under Mediterranean conditions, a close relationship was found by [9] between the yield obtained in each tillage system and rainfall during the crop cycle and noted that, above 300 mm of rainfall, conventional tillage gives higher yields compared to no-tillage and vice-versa. However, in the first year of our study, where rainfall was higher than 300 mm, the yield of the CT system as well as its main components resulted in being similar to those of MT and NT systems. This may be due to the excess of water in the period of soil preparation and the clay texture of the soil, which have interfered with the performance of an adequate seedbed for conventional tillage plots. This negatively affected the seeds germination since they have left uncovered, while superficial tillage and no-tillage techniques resulted in better seed germination conditions. Similarly, better seed emergence conditions in NT plots have improved spike density compared to minimum and conventional tillage in the second year (2020). According to [47], it is important to perform tillage operations in optimal soil moisture conditions. If the soil is tilled in wet conditions, large clods may be produced and soil structure as well as seed emergence may be damaged. Our results are in contradiction with the observations of [21], who noted a better spike density and seed emergence in CT than in the conservation tillage systems due to a better seedbed performance in less heavy soil in Southern Italy.

Grain quality did not significantly vary between the different tillage systems during the 2 years of the study except for grain vitreosity. Protein concentration is highly dependent on climatic conditions. In our study, similar protein levels were observed in the different treatments, which agrees with the findings of [23,30,45,46,48], while [9,38] found higher protein contents in NT under drought conditions, and [21,27,49] noted a superiority of CT in more humid conditions. On the other hand, grain vitreosity has been affected by tillage systems in the 2 years in different ways. It has been higher under conservation tillage systems compared to CT in the first year—due to more nitrogen leaching in the tilled soil after heavy rains in the beginning of the season. Yet, it has been lower in NT than in the other systems in the second year, due to lower N availability under NT in dry conditions. The authors of [17,50] affirmed that N mineralization is slower in untilled soils, and its loss via surface runoff is very frequent due to its surface application. Our results show also that the grain quality of durum wheat is less affected by the climatic variation between the 2 years under conservation tillage systems (NT and MT), while in wet conditions the grain vitreosity was significantly reduced under CT. Therefore, a stable and appreciable grain quality can be obtained under NT if the amount of applied N fertilizers is increased [45]. The test weight and the individual kernel weight are more affected by the year than by tillage or rotation. As the authors of [46] argue, the wet conditions in the first year of this study induced significantly higher test weight and thousand kernel weight compared to the second year, which is in agreement with the observations of [28]. Whereas, the three tillage systems gave similar grain weight in each year individually as well as on average of the 2 years, which is in concert with the findings of [21,30,47].

## 5. Conclusions

The results of this study show that the yield varies significantly between years depending on climatic conditions, which is typical for the Mediterranean environment. Tillage significantly affected the grain yield, particularly in dry conditions. NT resulted in being significantly higher than MT and CT in the dry year, which is mainly due to the better plant density as a result of the higher water storage and good seeds emergence conditions under this system. In the wet year, instead, the three tillage systems produced similar plants density and grain yield levels. The tillage-climate interaction had a significant effect on grain vitreosity of the durum wheat. CT produced lower grain vitreosity percentage in the wet year, while the vitreous aspect of the durum wheat grain did not significantly vary between the 2 years under conservation tillage (MT and NT).

The results of this study conducted in short-term tillage trial and specific soil and climate conditions support the conclusion that the CT system is a bad option in the area of study with regards to the time and energy needed for soil preparation—especially when compared to NT, which produces similar or better yields depending on the year and features a stability in grain quality despite the year conditions. However, the duration of the experiment is not sufficient to generalize this conclusion, and further research must be considered.

Looking ahead, it would be important to continue long-term experimentation to make further innovations and better adapt conservation agriculture practices. A starting point could be the management of crop residues, which can greatly affect the productivity and quality of durum wheat, but also soil fertility and structural conditions. These aspects could also be better exploited for the contribution to ecosystem services that conservation agriculture can develop from an economic point of view in the study region. This entails the potential to show the profitability of conservation agriculture from an economic as well as from an environmental perspective, and could help farmers with the adoption of this agronomic approach as compared to the conventional system commonly adopted in the arid agricultural areas of the Mediterranean basin.

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