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Tillage Systems Effect on Wheat Yield in the Saïs Region of Morocco

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Abstract Morocco is facing a significant threat to food grain production due to climate change, with an important incline in temperature and a decline in precipitation. Conservation agriculture (CA) is an important tool to confront soil fertility depletion and the adverse effects of climate change. The objective of this work was to compare and evaluate the impact of four cultivation techniques (no-till: NT, minimum till: MT, chisel ploughing: CP and deep ploughing: DP) on certain physiological and agronomic parameters of bread wheat. In this context, an experiment was fielded at the experimental station of Douyet of the National Institute of Agronomic Research of Meknes, Morocco during the 2019-2021 cropping seasons. The experimental design was a complete randomized block, with three replications. Results showed that the stomatal conductance and chlorophyll content revealed a significant effect in the end of flowering stage but no significant effect showed in the heading stage. NT showed the highest grain yield compared with other practices (DP, CP and MT). The decrease in grain yield registered in the first year was related to late sowing and to the drought stress caused by a low rainfall (135 mm) compared to the second year (377 mm). Moreover, the WUE in the NT obtained a higher value (6.36 kg ha^{-1} mm^{-1}) followed by CP (5.14 kg ha^{-1} mm^{-1}), DP (4.99 kg ha^{-1} mm^{-1}) and MT (4.89 kg ha^{-1} mm^{-1}). While in the second year, the NT registered a higher WUE (10.05 kg ha^{-1} mm^{-1}) than other cultivation practices DP (8.72 kg ha^{-1} mm^{-1}), MT (8.41 kg ha^{-1} mm^{-1}) and CP (8.31 kg ha^{-1} mm^{-1}).

Keywords Conservation Agriculture, Conventional Tillage, Bread Wheat, WUE, Grain Yield

1. Introduction

Morocco is heavily affected by climate variability; projections indicate that by 2050 aridity undergoes a further increase in temperature (+1.5°C) and a decrease in rainfall (-15%) [1]. Climate change affects all aspects of daily life, including the food supply. Moreover, it makes it more difficult to predict meteorological conditions for accurate and successful agricultural production [2]. Indeed, the increasing variability of rainfall and elevated frequency of droughts are likely to further reduce the availability of water. These constraints will have negative impacts on potential agricultural yields [1]. The cereal sector presents major socio-economic issues with a very important weight on the agricultural sector in Morocco. It is an essential part of the world's food security. The cultivated area in Morocco was 3.65M ha in 2019 with an average production of 8 million tons between 2015 and 2019 [3].

In addition, conventional systems of soil preparation and cultivation imply intensive and frequent tillage, causing soil degradation through erosion, compaction, reduced water holding capacity, and loss of soil carbon, while disturbing the habitats of surface and subsurface organisms and their niches, which result in a deterioration of soil quality, fertility, structure and soil organic matter, thus negatively affecting yield [4,5].

On the contrary, conservation agriculture has a critical role in providing food supply by increasing soil moisture, thereby increasing drought resistance and reducing the risk of crop failure [6]. Conservation agriculture (CA) relies on three integrated management principles of soil, water, and other agricultural resources to accomplish the goal of economically, ecologically and socially sustainable agricultural production: minimal soil disturbance, crop residue retention, and crop diversification (rotations and/or associations) [7]. Scientists have demonstrated a significant positive effect of CA on wheat production under dry Mediterranean climate [8,9]. The concept of CA developed from no-till (NT). In this system, seeds are planted without prior soil disturbance or with minimum mechanical soil disturbance [10]. The adoption of no-till has occurred over approximately 157 million hectares, of global arable land [11]. In Morocco, the area of conservation agriculture was 30 M ha in 2021 [12].

A large number of research support the idea that compared to conventional tillage, no-till has a greater potential to sequester carbon in the soil through no-till and the presence of soil cover [13], improve soil functioning and quality, and also reduce the soil erosion risk [14].

The value of a soil water conservation strategy is based on a stomatal regulation mechanism that conserves soil water in order to prolong the effective photosynthesis. Studies established that soil cover improves water retention in the soil by limiting water evaporation, runoff and by favoring water infiltration into the soil [15], and lower soil temperatures [16]. This allows conserving moisture and preventing soil drying [17].

CA helps to reduce weed pressure [18] and improve biological activity in the soil through the release of high amounts of biomass [19]. A study recorded that crop yields improved with the NT system under water-limited conditions [20]. In addition, other research revealed that the yield decreases in the year following the transition to no-till [21]. However, others have reported that after a period of three years, yields increase again [22]. Furthermore, a study showed that under no-till the yields increase of 1 t ha^{-1} compared to conventional practices after the 3rd year [23].

These contradicting results imply that no-till impacts may be supported by various variables, such as the environment (soil properties and climate) and management practices (tillage timing, crop type, fertilization) [24].

A field trial was conducted in an experimental station during two growing seasons, with the objectives to compare and evaluate the impact of four cultivation techniques (no-till, minimum till, chisel ploughing and deep ploughing) under favorable bour climate conditions in the Saïs region of Morocco on the agronomic traits of wheat and its physiological parameters.

2. Materials and Methods

2.1. Site Description, Experimental Design and Treatments

This investigation was conducted in two cropping seasons 2019-2020 and 2020-2021 at the experimental station of Douyet of the National Institute of Agronomic Research of Meknes, Morocco. The Saïs plain belongs to the favorable bour climate (34°2'N, 4°50'E, and altitude: 416m). Before setting up the experiment, soil samples were taken with manual auger at depths of 0 to 30 cm (for soil basic chemical analysis). Average soil samples were dried in an oven, homogenized, milled and sieved through a 2 mm sieve. Both the pH and electrical conductivity (EC) of the soil were determined in soil water solutions (1:2.5) [25]; organic matter (OM) was approximated using the wet digestion method of Walkley and Black [26]; phosphorus available (P) was estimated using $NaHCO_3$ method of Olsen [27]; available potassium (K) was extracted using CH_3COONH_4 by Stanford and English [28] (Table 1). The soil type at this station is silty-clay (48.50% silt and 39.90% clay and 11.60% fine sand), mainly dark Vertisols with limestone concretions, characterized by a fairly deep topsoil layer with pH is bit alkaline, rich in organic matter and potassium but very poor in phosphorus (Table 1). The annual average precipitation for the experimental site is 233 mm but the wheat crop received only 135 mm because the sown was at late December in 2019-2020 (dry season) and 408 mm in 2020-2021 but the wheat crop sown at mid-November received 377 mm (Table 2). The temperature ranged from 12.48°C (average minimum temperature) to 25.5°C (average maximum temperature) during the first growing season (Table 3), whereas during the second growing season, the temperature varied from 10°C to 22.1°C. The experimental design was a complete randomized block, with three replications. Tillage systems (DP- deep ploughing, CP- chisel ploughing, MT- minimum till and NT- no-till).

Table 1. Chemical and physical soil properties at the experimental site

OM (g kg^{-1})	EC (m s^{-1})	pH	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})
3.63	21.33	7.80	11.89	478.05

Table 2. Rainfall (mm) at the experimental site of Douyet

	November	December	January	February	March	April	May	June	Total
2020/2021	47	19.5	109	25.2	68	113.8	25	0	408
2019/2020	61.5	35.5	18	0	40	67.5	0	10	233

Table 3. Temperature (°C) at the experimental site of Douyet

	November	December	January	February	March	April	May	June
2020/2021	18.47	12.65	10	12.75	14.12	16.63	18.71	22.1
2019/2020	14.4	14.23	12.48	17.17	15.58	17.33	24.16	25.5

2.2. Plant Material Sampling and Analysis

Plant material samples were collected using a 1 m × 1 m frame randomly and diagonally in three repetitions in each tillage system. Wheat plant material was oven dried at 65°C to a constant weight to determine dry matter weight and then scaled to the hectare. Grain yield was computed at the same samples after manual harvesting and grain separation from the remaining plant material. The thousand kernels weight was measured by weighing 1000 seeds. Number of spikes m^{-2} and number of kernels m^{-2} were counted.

Water use efficiency (WUE) or water productivity of crop was determined by a ratio of grain yield (GY) to evapotranspiration (ET) [29], it's the ability of the plant to maximize carbon gain and reduce water loss.

$$WUE = GY/ ET \; ; \; ET = P + I + G \pm Q - \Delta S$$

ET includes rainfall (P), irrigation (I), ground water flow (G); neglected because soil input (P and/or I) does not exceed the soil storage capacity [30], runoff (Q); neglected due to the absence of slope [30] and soil water storage at the time of sowing and harvesting (ΔS) [31].

Stomatal conductance ($mm.s^{-1}$) and photosynthetic rate ($\mu mol.m^{-2}.s^{-1}$), are considered as an indicator of plant water status, were measured simultaneously on Delta; T type AP4 porometer. Three flag leaves of plants randomly selected were measured, after it had been standardized with a standard calibration plate according to the manufacturer's instructions.

Chlorophyll content (SPAD-units) is an indicator of plant physiological status and environmental stress. Three flag leaves were measured using the Chlorophyll Meter SPAD-502. Three measurements in the middle of the flag leaf were made randomly for each plant and the average sample was used for analysis.

Agronomic traits were measured in two successive seasons but the physiological parameter was only measured in the second season for two growth stages; end of heading (Zadoks growth stages Z59) [32] and end of flowering (Z69).

2.3. Data Analysis

Impact of tillage systems on yield components and physiological parameters of plants was examined by factorial ANOVA design and coefficient of variation using SPSS software 21.0. Means were compared by S-N-K test at a 5% confidence interval.

3. Results and Discussion

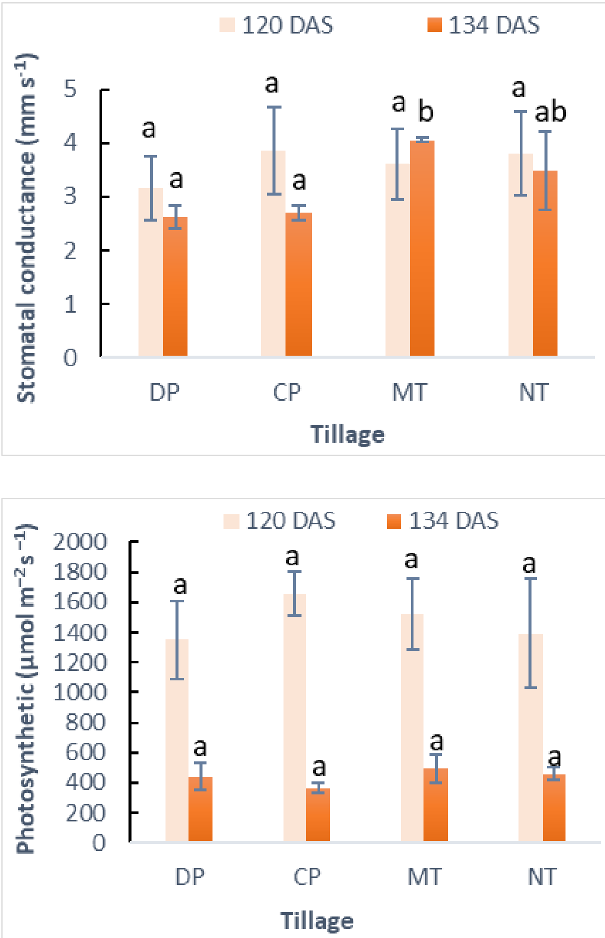
3.1. Gas Exchange

In 120th day after sowing (DAS) (Z59), stomatal conductance (gs) showed no significant differences under tillage systems, the gs values were similar compared to other tillage systems with an average 3.86 mm s^{-1} (CP), 3.80 mm s^{-1} (NT), 3.61 mm s^{-1} (MT) and 3.16 mm s^{-1} (DP). However, in 134th DAS (Z69), the gs parameter affected by the tillage systems, but the highest gs (4.06 mm s^{-1}) was recorded in the MT, followed by NT (3.74 mm s^{-1}), CP (2.71 mm s^{-1}) and DP (2.62 mm s^{-1}) systems (Fig. 1).

No significant effect was shown between tillage systems and photosynthetic active radiation (PR). The PR in 120th DAS (Z59), achieve the highest value in the CP (1658 $\mu mol\ m^{-2}\ s^{-1}$) system compared to other tillage systems, by 1523 $\mu mol\ m^{-2}\ s^{-1}$ (MT), 1394 $\mu mol\ m^{-2}\ s^{-1}$ (NT) and 1351 $\mu mol\ m^{-2}\ s^{-1}$ (DP), respectively (Fig. 1). On the other hand, in 134th DAS (Z69), the higher PR observed under MT (490 $\mu mol\ m^{-2}\ s^{-1}$) followed by NT (460 $\mu mol\ m^{-2}\ s^{-1}$), DP (440 $\mu mol\ m^{-2}\ s^{-1}$) and CP system (363 $\mu mol\ m^{-2}\ s^{-1}$) (Fig. 1).

Stomatal conductance is a primary physiological factor to optimize water use under drought conditions. In the present study, stomatal conductance was not affected by tillage systems in 120th DAS but showed a significant effect in 134th DAS. The higher stomatal conductance registered under no-till, thus indicates that higher photosynthetic and transpiration. A study reported that positive relationships were found between stomatal conductance and soil moisture [33]. Similarly, research indicated that tillage systems (CT, MT and NT) significantly affected the photosynthesis rate of maize plants [34]. In contrast, other research noted that stomatal conductance in the CT system was highest, whereas PR, not significantly differ from the MT system [35].

Under drought conditions, NT system increases water availability, thereby enhancing photosynthetic activity and consequently increasing yield over CT [36]. On the other hand, a study found no significant effects between tillage systems and stomatal conductance [37].



Deep ploughing (DP), Chisel ploughing (CP), Minimum till (MT) and No-till (NT). Stomatal conductance (gs); photosynthetic active radiation (PR). Bars represent the standard error. Different letters represent statistically significant differences between treatments ($p< 0.05$)

Figure 1. Impact of tillage systems on bread wheat gas exchange

3.2. Chlorophyll Content

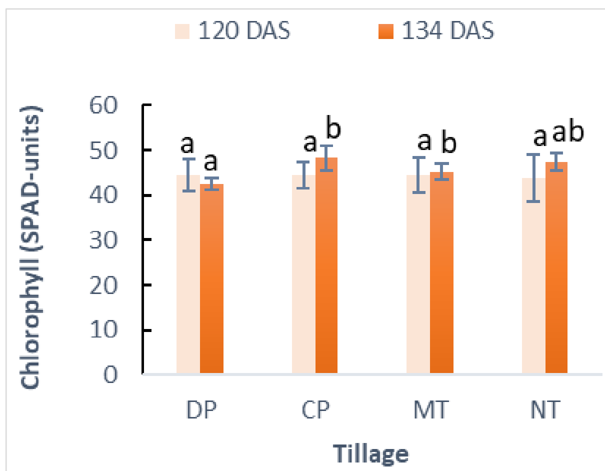
The analysis of variance of chlorophyll indicated no significant difference between cultural practices in 120th DAS (Z59), but showed a significant effect in 134th DAS (Z69). The chlorophyll content was similar in all cultural practices with an average of 44 SPAD-units in 120th DAS. In contrast, in 134th DAS, the higher chlorophyll content observed in CP (48.30 SPAD-units), NT (47.50 SPAD-units), MT (45.30 SPAD-units) and the lower chlorophyll value (42.47 SPAD-units) in DP (Fig. 2).

Chlorophyll content is a critical parameter directly influencing the absorption, transmission, and distribution of light energy and the efficiency of the photosynthetic activity [38]. In this study, chlorophyll content was significantly unaffected by tillage system in 120th DAS, according to a study found that the tillage system had no effect on the chlorophyll content of canola [39], also pointed out that tillage systems unaffected significantly the chlorophyll content of corn leaves [40]. The same result was recorded that no impact of tillage systems on physiological traits such as canopy development and water use efficiency, maturation rate was similar to canola under NT and CT [39]. On the other hand, another study reported that the chlorophyll content was significantly higher in the CT system than in the MT and NT systems [35].

Nevertheless, chlorophyll content was significantly affected by tillage system in 134 DAS. According to a study of wheat plants under drought condition, that obtained chlorophyll content better in minimal tillage systems (MT, NT), which led to improved photosynthesis in the later growth stages relative to the conventional system (CT) and increased grain yield [38]. The study also recorded that chlorophyll was significantly influenced by tillage practices [41]. The highest chlorophyll content found under NT compared to CT. The same result noted that chlorophyll content higher under NT [42].

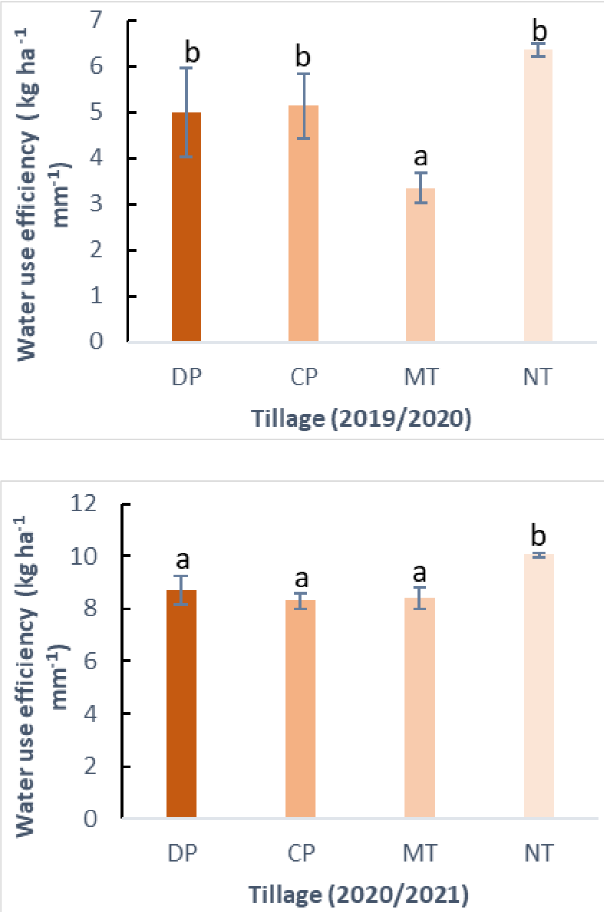
3.3. Water Use Efficiency

Water use efficiency (WUE) depended significantly on tillage systems in the first season, the highest WUE was found in NT (6.36 kg ha^{-1} mm^{-1}) in comparison to CP (5.14 kg ha^{-1} mm^{-1}), DP (4.99 kg ha^{-1} mm^{-1}) and MT (3.34 kg ha^{-1} mm^{-1}) (Fig. 3). Also, in the next year tillage systems affected significantly WUE, NT revealed a higher WUE (10.05 kg ha^{-1} mm^{-1}) followed by MT (8.79 kg ha^{-1} mm^{-1}), CP (8.41 kg ha^{-1} mm^{-1}) and DP (8.31 kg ha^{-1} mm^{-1}) systems almost showed a similar WUE (Fig. 3).



Deep ploughing (DP), Chisel ploughing (CP), Minimum till (MT) and No-till (NT). Bars represent the standard error. Different letters represent statistically significant differences between treatments ($p< 0.05$)

Figure 2. Impact of tillage systems on bread wheat chlorophyll



Deep ploughing (DP), Chisel ploughing (CP), Minimum till (MT) and No- till (NT). Water use efficiency (WUE). Bars represent the standard error. Different letters represent statistically significant differences between treatments ($p < 0.05$)

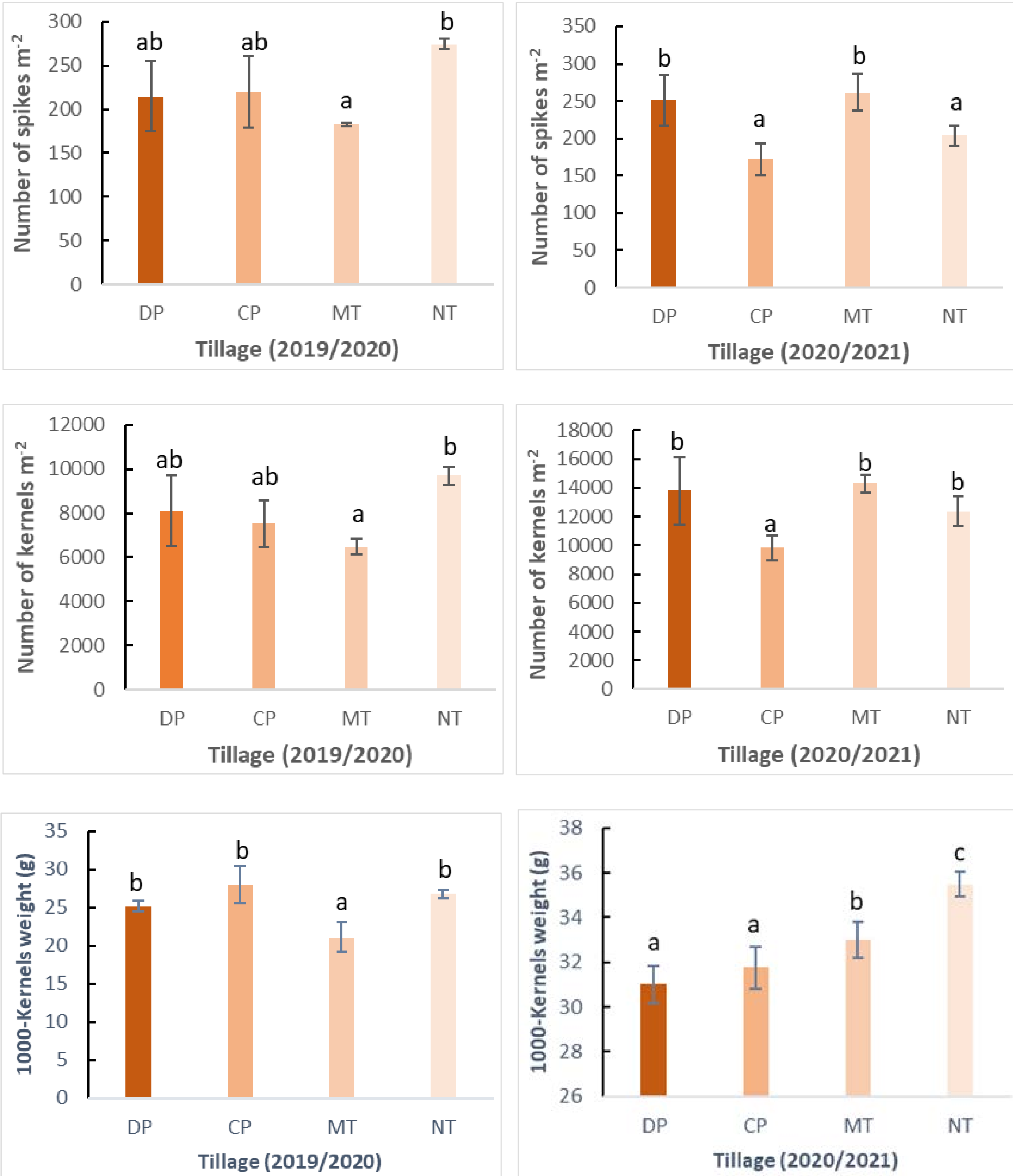
Figure 3. Impact of tillage systems on bread wheat water use efficiency

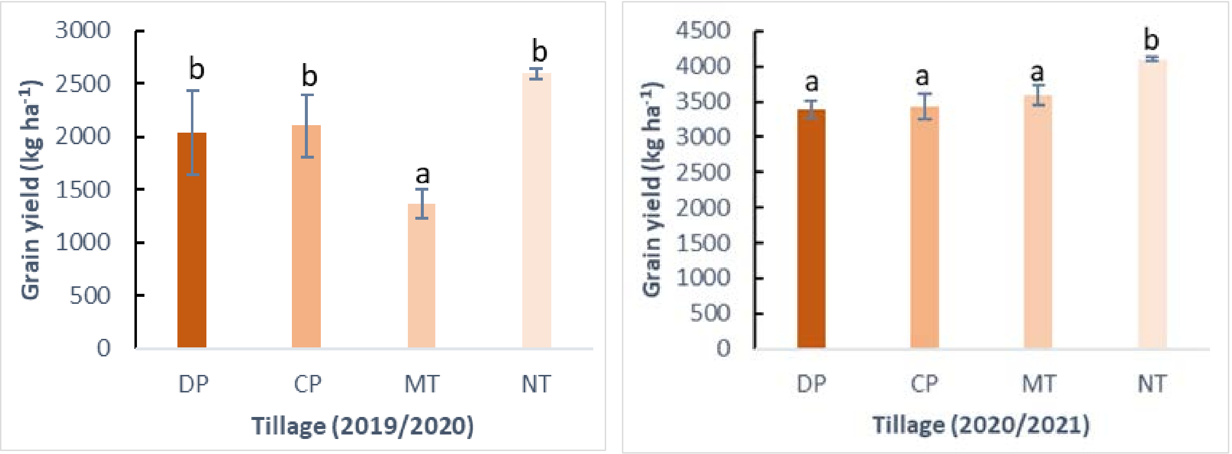
Water use efficiency (WUE) defines water use and water retention in the soil [29]. The analyses of variance showed that tillage systems indicated a significant effect on WUE, the lowest WUE shown in the CT system over to MT and NT. This result is similar to another research recorded that NT affect significantly maize WUE in northern China and wheat in northwestern China that improved it compared to CT [43]. One result indicated that NT improved soil nutrient, water infiltration and water storage capacity compared to CT [44]. Other studies obtained that NT enhanced WUE in case of residues retained [20,45]. The NT system has an effect on water storage capacity and attenuates drought stress throughout the cropping season compared to the CT system [46]. Under drought stress conditions, the NT system provides a benefit over CT system due to improved water availability, thus increasing photosynthetic activity and thus enhancing yield [36]. Consequently, water conservation potential translated into higher grain yields [47]. The reduction of soil water evaporation by residual cover under NT may enhance soil water content compared to CT, specifically during dry seasons, possibly the reason for higher wheat yield [48].

3.4. Grain Yield

The tillage systems in the first season showed a significant effect on yield components (number of spikes m^{-2}, number of kernels m^{-2} and 1000-kernels weight) and grain yield. The biggest number of spikes (NS) showed under NT (275) followed by CP (220), DP (215) and MT (183). Regarding number of kernels m^{-2} (NG), NT registered the highest NG (9396) compared to other cultural practices DP, CP and MT with an average 8112, 7525 and 6466, respectively. The greater 1000-kernels weight was obtained in CP (28 g), followed by NT (27 g), DP (25 g) and MT (21 g). NT revealed a higher grain yield compared with other cultural practices (CP, DP and MT) with an average 2597 kg ha^{-1}, 2102 kg ha^{-1}, 2040 kg ha^{-1} and 1364 kg ha^{-1}, respectively. This decrease in the grain yield registered related to late sowing and to the drought stress caused by decrease of rainfall during this cropping seasons, the annual rainfall was 135 mm (Fig. 4).

Similarly, in the second year, the number of spikes m^{-2}, number of kernels m^{-2}, 1000-kernels weight and grain yield were significantly affected by tillage systems. The higher number of spikes registered under MT (262) followed by DP (251), NT (204) and CP (172). Similarly, the higher number of kernels revealed under MT (14274) followed by DP (13783), NT (12357) and CP (9829). However, the higher 1000-kernels weight showed under NT (35g) compared to MT (33 g), CP (32 g) and DP (31 g), respectively. Regarding grain yield, the results recorded that the NT showed the highest grain yield (4106 kg ha^{-1}) followed by MT (3588 kg ha^{-1}), CP (3435 kg ha^{-1}) and DP (3394 kg ha^{-1}) (Fig. 4).


Number of spikes m-2
300
250
200
150
100
50
0
ab
ab
a
b
DP
CP
MT
NT
Tillage (2019/2020)
Number of spikes m-2
350
300
250
200
150
100
50
0
b
a
b
a
DP
CP
MT
NT
Tillage (2020/2021)
Number of kernels m-2
12000
10000
8000
6000
4000
2000
0
ab
ab
a
b
DP
CP
MT
NT
Tillage (2019/2020)
Number of kernels m-2
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
b
a
b
b
DP
CP
MT
NT
Tillage (2020/2021)
1000-Kernels weight (g)
35
30
25
20
15
10
5
0
b
b
a
b
DP
CP
MT
NT
Tillage (2019/2020)
1000-Kernels weight (g)
38
36
34
32
30
28
26
a
a
b
c
DP
CP
MT
NT
Tillage (2020/2021)



Deep ploughing (DP), Chisel ploughing (CP), Minimum till (MT) and No-till (NT). Bars represent the standard error. Different letters represent statistically significant differences between treatments ($p < 0.05$)

Figure 4. Impact of tillage systems on bread wheat yield and yield components

Results showed that yield and yield components under NT was significantly higher than CT system in two cropping seasons. The temperature and soil type in Douyet are likely responsible for these variations. Cultural practices may contribute to mitigating the adverse effect of thermal winds (Sirocco) present in the Douyet area at the end of the crop cycle [49]. Similarly assigned by a study the increase in 1000-kernels weight due the moisture retention benefit from maintenance of surface crop residue under reduced tillage and no-till compared to conventional tillage [50]. This result is consistent with research that found the grain yield in conventional tillage systems lower than in other tillage systems [51]. In agreement with another study that noted the highest grain yield obtained under minimum tillage compared to conventional tillage, dependent to great extent on soil moisture under no-till [52], retaining the total soil pore space while maintaining exchanges between the soil macro- and micro-pores [53]. Moreover, a study displayed that soil water storage is beneficial to the crop under NT conditions, especially in the grain filling period after anthesis stage [54]. Same results shown by others that NT increase wheat yields in the dry areas than CT [20,55]. Others studies in line with this result stated that MT and NT had positive effects on cereal yield [56,57]. Also, a study showed that yield components affected by tillage systems in the second season grain yield were significantly higher in the NT system [58]. Another result in disagreement revealed that barley and wheat grain yield decrease under no-till [59]. In addition, other studies showed that the grain yield was significantly higher under CT compared to MT and NT [35,60]. In addition, results from two years of research indicated that agronomic attributes of the wheat crop showed greater changes because of the variability of climate conditions. In specific, the average temperature in 2020 was higher compared to 2021. The wheat yield in 2020 was significantly lower due to less precipitation, resulting in a noticeable reduction in seed yield compared to 2021. In line with a study that signaled that the higher temperature at the end of the crop cycle was causing a decrease in wheat yields [61]. Grain yield response to tillage systems depends on soil type, crop species, rainfall, and climate conditions [62].

4. Conclusions

In Morocco, the adoption of a no-till system could be an alternative for improving wheat production. No-till allowed to conserve soil moisture consequently increased grain yield and WUE compared to the conventional tillage treatment in the favorable bour climate.

No-till influenced significantly grain yield and yield components in two successive years on the Vertisols in the Saïs region of Morocco.

Tillage systems significantly affect some physiological parameters at the end of the flowering stage, which may cause moisture storage.

In general, the improvement in wheat yield under conservation tillage systems was probably caused by temperature and moisture stresses in the late growth phases of the plant and also by the decrease of plant residues in conventional tillage.

Other medium and long-term studies should confirm or infirm the effects of no-till on behavior and wheat yield in the Saïs region of Morocco.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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