Journal of Agriculture and Food Research 14 (2023) 100900

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Seed yield, physiological and biochemical attributes in canola (*Brassica napus* L.) as influenced by tillage system and cropping season

Wafae Sellami [a,b], Abderrazzak Bendidi [a], Mohammed Ibriz [b], Abdelghani Nabloussi [c], Khalid Daoui [a,*]

[a] Research Unit of Agronomy and Plant Physiology, Regional Center of Agricultural Research of Meknes, National Institute of Agricultural Research, Avenue Ennasr, PO. Box 415, Rabat 10090, Morocco
[b] Crop and Animal Production and Agro-Industry, University of Ibn-Tofail, Faculty of Sciences, PO Box 133, Kenitra 14000, Morocco
[c] Research Unit of Plant Breeding and Plant Genetic Resources Conservation, Regional Center of Agricultural Research of Meknes, National Institute of Agricultural Research, PO. Box 415, Rabat 10090, Morocco

ARTICLE INFO

Keywords:
Canola cultivation
No-till
Mediterranean conditions
Tillage effect
Oil yield
Chlorophyll content

ABSTRACT

Canola is an important oilseed crop and its performance was influenced by tillage system. However, no study on this influence has been carried out in North Africa. Also, the effect of tillage system on physiological and biochemical traits in canola has never been investigated. Therefore, the objective of this study was to evaluate the effect of tillage system on agronomic, physiological, and biochemical traits in canola during two cropping seasons (2019/2020 (Y1) and 2020/2021 (Y2)) under Moroccan conditions. The experiment was conducted according to a complete random block design with three replications and the tillage systems studied were deep ploughing (DP), chisel ploughing (CP), minimum till (MT), and no-till (NT). Over both seasons, tillage significantly affected all traits except for proline content. Notably, NT consistently exhibited superior performance with the highest seed yield (272 kg ha^{-1} in Y1, 1760 kg ha^{-1} in Y2) and oil content (36 % in Y1, 44 % in Y2). In contrast, DP faced challenges during severe drought in Y1, resulting in no production. On the other hand, in Y2, DP showed the highest stomatal conductance and sugars content, while NT exhibited the highest chlorophyll content. Considering these findings, no-till can be recommended for canola cultivation in Morocco as well as in other North-African and Mediterranean countries with similar climate and soil conditions.

1. Introduction

Canola (*Brassica napus* L.) production has economic and agronomic advantages. It is grown as one of the most important oil seeds, accounting for the world's second vegetable oil production after soybean. In 2021, world canola production was 71.33 million tons, while its global oil production reached 25 million tons [1]. In Morocco, oil seed crops area was 32.500 ha in 2019, including 22.207 ha of sunflower and 10.304 ha of rapeseed, ensuring a national production that covers only 1.7 % of domestic market needs in seed oils [2].

Agriculture sector is heavily impacted by climate change. Predictions indicate that, in 2050, aridification will undergo a further increase in temperature and a decrease in rainfall [3]. As a result, changes in the hydrological cycle (low precipitation) may cause a moisture deficit under rainfed cultivation [4] and high temperatures at flowering stage may decrease number of seeds, resulting in a significant decline in yield [5,6]. In all these complexities, agriculture still holds the potential to adapt to climate change through reducing or eliminating tillage [7].

Conservation agriculture (CA) is a system based essentially on minimal tillage (or no-till), cover crop residues, and crop rotation [8]. No-till (NT) is a system where tillage is eliminated and, with specific planting material, the soil is not disturbed [9]. Crop production under no-till has been increasing in Morocco from 4000 ha in 2013 to 30 000 ha in 2021 [10,11]. NT is designed to increase the ecological relationship among plants, soil and microorganisms [12]. Whereas conventional tillage alters soil biological activity [13] and depletes the physicochemical properties of soil [14]. NT can improve soil structure by increasing water infiltration and retention, reduce soil erosion by providing ground cover, increase soil fertility, and may result in lower greenhouse gas emissions [15,16]. Lenssen et al. [17] showed that NT improved soil water storage versus conventional tillage. Similarly, Yang et al. [18] established that NT conserved soil and water, minimized soil erosion through soil cover or minimal soil disturbance, and improved soil

* Corresponding author.
E-mail address: khalid.daoui@inra.ma (K. Daoui).

https://doi.org/10.1016/j.jafr.2023.100900
Received 8 November 2023; Received in revised form 17 November 2023; Accepted 29 November 2023
Available online 3 December 2023
2666-1543/© 2023 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Abbreviations used

DP	(Deep ploughing)
CH	(Chisel ploughing)
MT	(Minimum till)
NT	(No-till)
CT	(Conventional tillage)
NPP	(Number of pods per plant)
NSP	(Number of seeds per plant)
TSW	(1000-seeds weight)
DM	(Dry matter)
SY	(Seed yield)
HI	(Harvest index)
OC	(Seed oil content)
OY	(Oil yield)
Gs	(Stomatal conductance)
SS	(Sugars content)

organic matter content [19,20]. CA has many advantages in improving soil nutrients and crop yields over conventional tillage [21–24]. Johnston et al. [25] noted that no-till improved canola yields by 1–14 % over conventional tillage through enhanced soil water retention. Sainju et al. [26] also found that no-till increased canola growth and oil content under wet conditions. However, other reports indicated that canola yields were not significantly influenced by tillage systems [27–29]. In contrast, Holman et al. [30] established that conventional tillage enhances canola productivity about 8 % more than no-till. As one could notice, controversial findings were reported in those different studies, which might be due to environmental differences among the areas where the studies were carried out, particularly in climate and soil. Therefore, there is a need to further investigate the effect of tillage systems on canola growth and yield, mainly in areas that have not been experimented before. To our knowledge, there has been no research of no-till impact on canola performance under North-African environmental conditions. Furthermore, and over the world, the effect of tillage system on biochemical and physiological traits in canola has not yet been studied.

This is the first study conducted in Morocco with regard to the influence of tillage systems on canola, involving a multi-traits approach, to investigate and indicate the appropriate sowing practice in the actual context of climate change.

2. Materials and methods

2.1. Site description, experimental design and treatments

A field experiment was conducted at the Experimental Station of Douyet (National Institute of Agronomic Research of Meknes, Morocco) (34° 2′ N, 4° 50′ E; altitude: 416 m) during two cropping seasons (2019/2020 and 2020/2021).

The soil texture was silty-clayey (48.50 % silt, 39.90 % clay, and 11.60 % fine sand), with dark Vertisols and limestone concretions and a relatively deep topsoil layer. The principal soil properties (0–20 cm depth) on the site are as follows: pH was 7.8 (extracted by H_2O); organic matter (OM) is 1.62 g kg^{-1} (extracted by $K_2Cr_2O_7$ using the method of Walkley & Black); phosphorus available (P) is 11.89 mg kg^{-1} (extracted by $NaHCO_3$ using the Olsen method), and available potassium (K) is 477.5 mg kg^{-1} (extracted by CH_3COONH_4 using the method of Stanford and English).

The experimental design was a randomized complete block design (RCBD) with three replications. Plots size was 2.5 m by 10 m, with 30 cm row spacing. The tillage systems studied are deep ploughing, chisel ploughing, minimum till, and no-till. Deep tillage system (DP) was characterized by three consecutive passages: One passage using deep ploughing discs (30–35 cm), followed by two cover-crop passages. Chisel ploughing (CP) consisted of two successive passages, one with a chisel and one with cover-crop, at a depth of 20–25 cm. Minimum till (MT) was made through a single passage using cover-crop at a depth of 10–15 cm. No-till system (NT) consisted of using a no-till drill, only disturbing 5 cm-top layer of the soil.

Average rainfall in the first year (Y1) throughout the crop cycle was about 234 mm (the crop received only 135 mm because the sowing was late at the end of December), which was much lower than the average recorded in the second year (Y2) (408 mm). Rainfall during the second growing season was well distributed throughout crop growth stages. Also, mean temperature was higher in Y1, ranging from 13 °C (average minimum temperature) to 26 °C (average maximum temperature), while in Y2, the temperature ranged from 10 °C to 22 °C (Table 1).

2.2. Plant material, crop management and measurements

Plant material used in this study was the Moroccan rapeseed variety 'Baraka' (INRA-CZH3) developed by the 'Institut National de la Recherche Agronomique' (INRA-Morocco). This is an inbred line registered in 2018. This variety showed the highest germination percentage, the greatest agronomic performance, and the highest tolerance to waterlogging at different stages of plant growth, compared to other varieties [31].

Sowing was done on mid-December in 2019/2020 cropping season (Y1) and mid-November in 2020/2021 (Y2). All plots were treated with glyphosate at a rate of 3.36 kg dry matter per hectare (3 l/ha) during pre-planting. The seeding rate was 5 kg ha^{-1} for all the tillage systems used in this study. Plots received DAP fertilizer (18 % N_2, 46 % P_2O_5, 0 % K_2O) at planting in the two cropping seasons and received 50 kg N ha^{-1} as ammonium nitrate (33 %) during plant branching period only in the second season due to drought occurring in the first season.

During crop growth, stomatal conductance (mm.s^{-1}) was measured using Delta-T type AP4 porometer. Chlorophyll content was measured using Chlorophyll Meter SPAD-502. Five plants randomly taken for each treatment and then three leaves from each plant were taken to measure both parameters. The physiological parameters were measured at three growth stages: beginning bloom (D1: 129 days after sowing), bloom (D2: 143 days after sowing), and end of flowering (D3: 164 days after sowing).

Proline content was measured using the method of Monneveux and Nemmar [32], and the sugars content was measured according to the phenol-sulfuric method [33] at bloom stages. These two biochemical parameters were expressed in mg per gram of fresh weight.

Physiological and biochemical parameters were measured only in the second year (Y2) due to the constraints and restrictions imposed by the COVID-19 health crisis during the first year of this study.

For biomass and yield attributes, a random sample of 10 plants was harvested from each elementary plot, oven dried at 65 °C for 3 days, and then weighed to determine the aboveground biomass. Seed yield (SY)

Table 1
Climatic condition in the Experimental Station of Douyet during 2019/2020 and 2020/2021 cropping seasons.

	2019/2020		2020/2021	
	T (°C)	**P** (mm)	**T** (°C)	**P** (mm)
November	14	62	18	47
December	14	36	13	20
January	12	18	10	109
February	17	0	13	25
Marsh	16	40	14	68
April	17	68	17	114
May	24	0	19	25
June	26	10	22	0
Mean (T)/Cumulative (P)	18	234	16	408

was determined after threshing, cleaning, oven drying, and weighing seed samples. Also, number of pods per plant (NPP), number of seeds per plant (NSP), and 1000-seeds weight (TSW) were determined. Harvest index was computed as the ratio of seed yield to the aboveground biomass yield. Nuclear magnetic resonance (Oxford Analytical Instruments Limited) was used to determine seed oil content. Oil yield was calculated using the formula: Oil yield (kg ha^{-1}) = Oil content (%) * Seed yield (kg ha^{-1})/100.

2.3. Statistical analysis

An analysis of variance (ANOVA) was used to test the significance of differences among the four tillage techniques investigated for each of the parameters studied. Tillage systems (treatment) was considered as fixed factor. Treatment means were compared using SNK- test. The statistical software SPSS (IBM SPSS, Version 22) was used to perform the statistical analyses.

3. Results

3.1. Yield and its components

In Y1, analysis of variance showed significant differences among tillage systems for seed yield and its components number of pods per plant (NPP), number of seeds per plant (NSP), and 1000-seeds weight (TSW). NT system produced the highest seed yield (272 kg ha^{-1}), followed respectively by CP (145 kg ha^{-1}) and MT (101 kg ha^{-1}), while DP allowed no production as a result of the severe drought occurring in 2019/2020 cropping season. According to SNK-test, two classes were registered: the first class included only NT, followed by CP, MT, and DP in the second class. Regarding NPP, NT had the highest mean value (25), followed by MT (20) and CP (17). For NSP, once again NT showed the highest average (249), followed by CP (157), and MT (130). Similarly, TSW was highest under NT, with an average of 3.61 g, followed by CP (3.11 g) and MT (2.59 g) (Table 2).

Like Y1, significant differences were observed among tillage systems on yield and yield components (NPP, NSP, TSW) in Y2. NT revealed the highest seed yield (1760 kg ha^{-1}), followed by DP (1673 kg ha^{-1}), MT (1646 kg ha^{-1}), and CP (1550 kg ha^{-1}). According to SNK-test, two classes were observed. The first class was made up by NT, DP, and MT, while the second one included only CP. For NPP, DP had the highest mean value (302), followed by CP (105), MT (103), and NT (96). Regarding NSP, NT showed the highest average (1619), followed by DP (1566), MT (1446), and then CP (1205). However, the best TSW was found under CP (4.28 g), followed by MT (3.80 g), NT (3.63 g), and finally DP (3.57 g) (Table 2).

3.2. Dry matter and harvest index

ANOVA results showed that tillage system influenced significantly dry matter (DM) and harvest index (HI) in two cropping seasons.

In Y1, the highest DM was obtained under NT (459 kg ha^{-1}), followed by MT (345 kg ha^{-1}) and CP (342 kg ha^{-1}). However, in Y2, NT showed the lowest dry matter (2134 kg ha^{-1}) followed by MT (2156 kg ha^{-1}), CP (2261 kg ha^{-1}), and finally DP (4294 kg ha^{-1}).

In Y1, NT registered the highest HI (0.59 %) compared to other tillage systems, CP and MT, with an average of 0.42 % and 0.29 %, respectively. Likewise, in the Y2, the highest HI was observed under NT (0.25 %), followed by MT (0.23 %), CP (0.21 %), and DP (0.12 %) (Table 2).

3.3. Oil content and oil yield

In two cropping seasons, ANOVA results showed that tillage system affected significantly seed oil content (OC) and oil yield (OY).

In Y1, the highest OC was recorded under NT system (36 %), followed by CP (32 %) and MT (31 %). Similarly, in Y2, NT revealed the highest OC with an average of 44 %, compared to MT, DP, and CP with an average of 43 %, 41 %, and 39 %, respectively. SNK-test in Y2 indicated two classes, the first class included NT and MT, while the second one comprises DP and CP (Table 2).

Regarding OY, in Y1, NT revealed the highest mean value (99 kg ha^{-1}), followed by CP (47 kg ha^{-1}) and MT (31 kg ha^{-1}). According to SNK test, two homogeneous classes were recorded: the first class was made up by only NT, whilst the second included MT, CP, and DP. Like Y1, NT registered in Y2 the higher OY (768 kg ha^{-1}), followed by MT (706 kg ha^{-1}), DP (683 kg ha^{-1}), and CP (606 kg ha^{-1}). According to SNK test, three classes were identified: the first one with NT, the second with MT and DP, and the third with CP (Table 2).

3.4. Tillage effect on physiological and biochemical traits

Analysis of variances indicated that tillage system influenced significantly all parameters measured (stomatal conductance, chlorophyll content and sugars content), except for proline content.

Regarding stomatal conductance (Gs) in D1 (129 DAS), three SNK homogeneous groups could be identified. The first group contains MT with an average value of 3.90 mm s^{-1} and CP with a mean value of 3.81

Table 2
Tillage effect on canola number of pods per plant (NPP), number of seeds per plant (NSP), 1000-seeds weight (TSW), dry matter (DM), seed yield (SY), harvest index (HI), oil content (OC), oil yield (OY) during two consecutive cropping seasons.

2020/2021								
Tillage Systems	NPP (number)	NSP (number)	TSW (g)	DM (kg ha^{-1})	SY (kg ha^{-1})	HI (%)	OC (%)	OY (kg ha^{-1})
DP	302b	1566b	3.57a	4294b	1673b	0.12a	41a	683b
CP	105a	1205a	4.28b	2261a	1550a	0.21b	39a	606a
MT	103a	1446b	3.80a	2156a	1646b	0.23b	43b	706b
NT	96a	1619b	3.63a	2134a	1760b	0.25b	44b	768c
Significance	**	**	**	**	**	**	**	**
2019/2020								
Tillage Systems	NPP (number)	NSP (number)	TSW (g)	DM (kg ha^{-1})	SY (kg ha^{-1})	HI (%)	OC (%)	OY (kg ha^{-1})
DP	0a	0a	0a	0a	0a	0a	0a	0a
CP	17b	157b	3.11c	342b	145a	0.42c	33c	47a
MT	20b	130b	2.59b	345b	101a	0.29b	31b	31a
NT	25b	249b	3.61d	459b	272b	0.59d	36d	99b
Significance	**	*	**	*	*	**	**	*

DP: deep ploughing; CP: chisel ploughing; MT: minimum till; NT: no-till. ns stands for non-significant, * stands for significant differences at 5 % probability level and ** stands for significant differences at 1 % probability level. Different letters on the same column indicate significant differences among treatments according to SNK-test ($p < 0.05$).

mm s^{-1}. The second group comprises DP having an average of 3.15 mm s^{-1}. The last group is made up only by NT (2.67 mm s^{-1}). In D2 (143 DAS), SNK-test revealed four classes: DP is in the first class (3.11 mm s^{-1}), NT (2.74 mm s^{-1}) in the second class, CP (2.24 mm s^{-1}) in the third class, and finally MT (1.79 mm s^{-1}) in the last class. In D3 (164 DAS), three classes were observed: the first class included DP with the highest Gs (1.32 mm s^{-1}), followed by CP (0.75 mm s^{-1}) and MT (0.68 mms^{-1}) in the second class, and NT (0.39 mm s^{-1}) in the last class (Fig. 1).

Concerning chlorophyll content, in D1, three classes were found, the first class included NT (49 SPAD-units), the second class included MT (48 SPAD-units), and the last class included CP and DP systems with a mean value of 47 SPAD-units. In D2, SNK-test revealed two classes: the first class included NT, CP and MT with an average of 56 SPAD-units, while the second class included only DP with an average of 52 SPAD-units. In D3, SNK-test showed three classes: the first class included NT (49 SPAD-units), followed by MT (48 SPAD-units) in the second class, while the last class included CP and DP (45 SPAD-units) (Fig. 2).

Maximum proline content was recorded under MT (4.07 mg g^{-1}), followed by DP (3.65 mg g^{-1}), CP (3.17 mg g^{-1}), and NT (2.38 mg g^{-1}). Regarding sugars content, SNK-test showed two classes: the first class included DP (0.26 mg g^{-1}), succeeded by NT (0.10 mg g^{-1}), MT (0.09 mg g^{-1}), and CP (0.07 mg g^{-1}) in the same class (Fig. 3).

4. Discussion

The results of this study highlighted the significant influence of tillage systems in canola on agronomic, physiological, and biochemical traits, namely number of pods per plant (NPP), number of seeds per plant (NSP), 1000-seeds weight (TSW), dry matter (DM), seed yield (SY), harvest index (HI), seed oil content (OC), chlorophyll content (Chl), stomatal conductance (Gs) and sugars content (SS). The highest SY was obtained under no-till system (NT), with a mean superiority of 22 % over deep ploughing (DP) under Sais region conditions during two years. Notably, in the first year, DP yielded nothing due to drought conditions. In the second year, the yield difference increased to 5 %, possibly indicating the adaptability of NT. Previous studies had also found SY in canola was higher under NT than conventional tillage (CT), with a superiority ranging from 1 to 99 % depending upon soil moisture storage [25,34,35]. In contrast, other studies reported higher yield under CT [29,30,35–38]. On the other hand, Sainju et al. [26] found no significant differences among tillage systems. It has been documented by Soane et al. [39] and Thierfelder et al. [40] that yield under NT increased in the year after transition or after a period of three years. Seed yield is determined by pods per square meter (m^2), seeds per pod and individual seed weight [41]. Under NT system, NSP and TSW were improved compared to the other practices. Even though NPP was higher under DP compared to NT, it resulted in a lower seed yield, which may be related to a lower NSP and TSW. Typically, SY is more correlated to NPP than NSP [42]; however, our findings exhibited that SY was rather associated with NSP, which is in accordance with Zhang et al. [41] who found that NSP essentially plays a significant part in yield raise. There are negative correlations between these three yield components, being crucial to understand source-sink relationships [43].

Oil yield (OY) under NT was 27 % higher than DP. This can be explained by highest oil content (OC) obtained under NT, in addition to highest SY. This is in agreement with Sainju et al. [26]. Highest OC and OY were found to be related to the relatively higher soil moisture under NT compared to the other tillage systems. In fact, it was reported that *Brassica* species are sensitive to extreme (very high/very low) soil temperature and low moisture during flowering and pod filling, which can affect negatively oil content [44,45].

Highest DM and lowest HI were obtained under DP system. In contrast, lowest DM coupled to highest HI was observed under NT system, which confirms the finding of Gandía et al. [46] who reported that NT system seems to ensure superior canola grain formation and Miersch et al. [47] who noted that high canola seed yield was associated with low biomass and high HI. Nevertheless, our results are in contrast with those of Sainju et al. [26] on canola and Iboyi et al. [45] on Ethiopian mustard (*B. carinata*) reporting that aboveground biomass was not affected by cultural practices.

In this study, effect of tillage systems on some physiological and biochemical traits in canola was investigated for the first time. We observed that DP system showed the highest Gs and SS content. This is likely due to the DP system promoting better vegetative growth, resulting in increased leaf area, enhanced photosynthesis, and ultimately higher stomatal conductance, leading to increased sugar production. However, the DP system had lower SY compared to the NT system, suggesting that the DP system may have been less effective in supporting seed formation and development. Our finding is in agreement with Buczek et al. [48] in wheat and Saleem et al. [49] in cotton, who observed that Gs was highest under CT than NT. On the other hand, Habbib et al. [50] in wheat and Iboyi et al. [51] in Ethipian mustard found that Gs was not influenced by tillage systems. This contrasting finding might be related with climate events during growth stage. Regarding chlorophyll content, the highest value was obtained under NT compared to other practices, which is in line with Jiang et al. [52], Wu

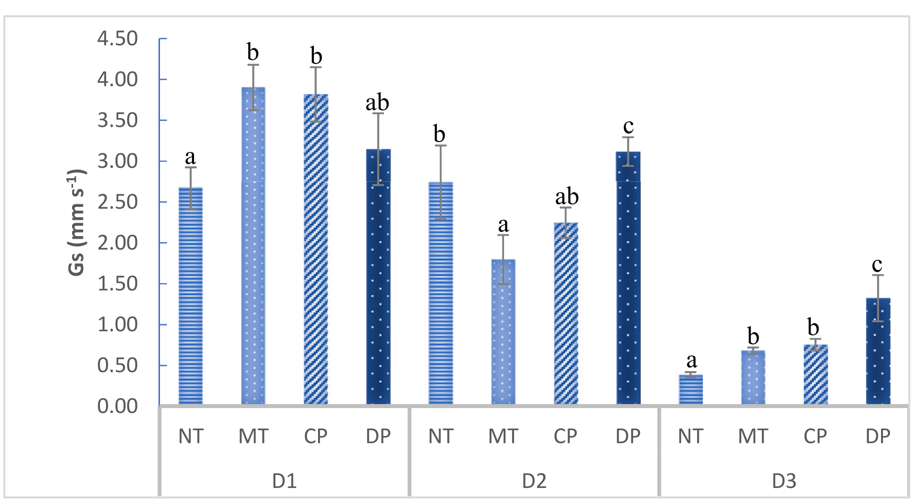

Fig. 1. Tillage effect on stomatal conductance (mm s^{-1}) during 2020/2021 cropping season.
Different letters indicate significant differences between treatments according to SNK-test ($p < 0.05$). The bars represent the standard error. DP: deep ploughing; CP: chisel ploughing; MT: minimum till and NT: no-till. D1 (129 days after sowing), D2 (143 days after sowing) and D3 (164 days after sowing).

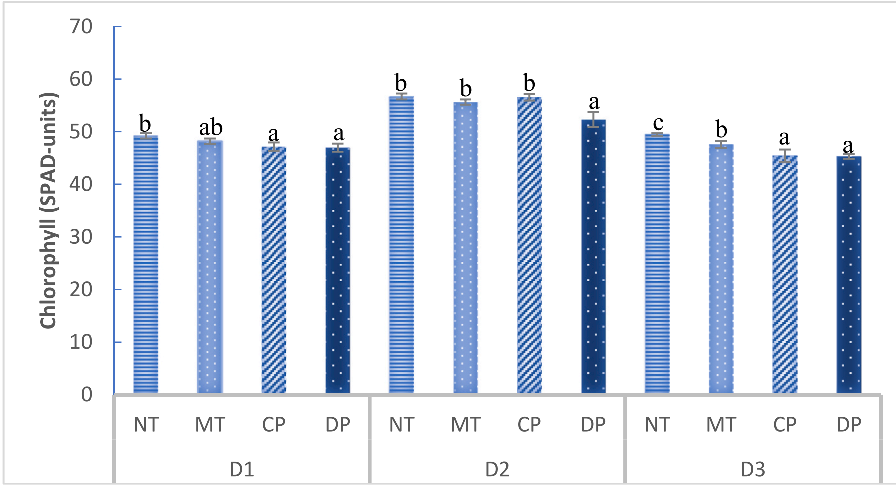

Fig. 2. Tillage effect on chlorophyll (SPAD-units) during 2020/2021 cropping season.
Different letters indicate significant differences between treatments according to SNK-test ($p < 0.05$). The bars represent the standard error. DP: deep ploughing; CP: chisel ploughing; MT: minimum till and NT: no-till. D1 (129 days after sowing), D2 (143 days after sowing) and D3 (164 days after sowing).

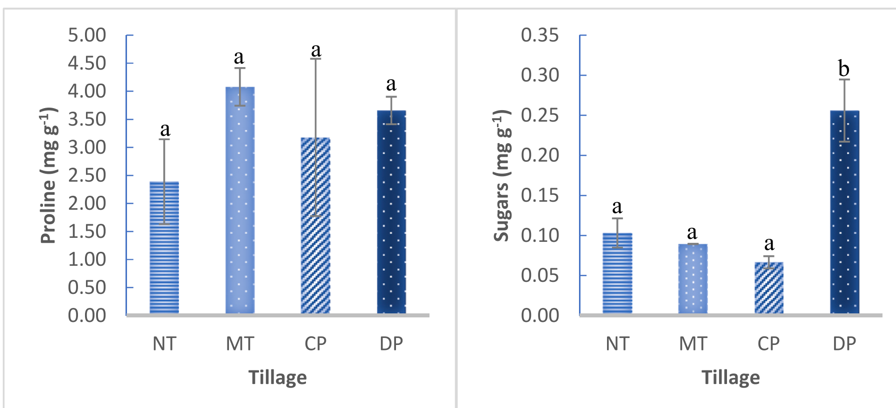

Fig. 3. Proline and sugars contents responses to tillage systems.
Different letters indicate significant differences between treatments according to SNK-test ($p < 0.05$). The bars represent the standard error. DP: deep ploughing; CP: chisel ploughing; MT: minimum till and NT: no-till.

et al. [53], and Hou et al. [54] having all worked on wheat. This was mainly due to the enhanced soil water storage under NT, which improved photosynthetic activity.

In addition, results of this two-year study indicated a significant impact of climate variability on canola seed yield, oil content, and oil yield. Average temperature in the first year was higher than in the second one, while rainfall was lower in the first year compared to the second one (Table 1). These conditions resulted in lower SY in the first year. Besides, during the same year, absence of nitrogen fertilization accentuated the yield decrease, which is in accordance with Borstlap and Enz [36], Rharrabtia et al. [55] and Debiase et al. [56]. Similarly, other previous studies indicated that oil yield was lower under dry conditions compared to wet conditions, implying that higher rainfall and lower temperatures were favorable for higher oil yield in canola [25,57–59]. Although SY and OY were influenced negatively by the climate variation, no-till system (NT) has always shown higher values, compared to the other tillage systems. This may be due to reduced soil disturbance, under NT conditions, thus preserving soil structure and moisture, while increasing organic matter [19,20]. This technique also minimizes soil erosion and promotes nutrient uptake [21,23], creating an optimal environment for canola cultivation, consistently yielding more than other tillage methods.

5. Conclusion

This study highlighted that NT system is well adapted to Mediterranean (Moroccan) conditions, exhibiting its superiority over the other tillage systems for chlorophyll content, seed yield, seed oil content, and oil yield. Besides, NT ensures higher soil moisture and lower plant transpiration because of lower stomatal conductance, compared to other tillage systems. Therefore, NT should be recommended for canola growers in Morocco as well as in other Mediterranean countries with similar climate and soil conditions. Nevertheless, to optimize canola yields under NT system, further studies on varietal (genotypic) specific adaptation, timely planting, proper residue management, effective weed control measures, and appropriate fertilization are needed. Also, the effects of different tillage systems on soil properties, which in turn influence plant growth and food quality, should be investigated.

Funding

This research was financed by INRA-ICARDA project MGCP (2020–2024).

CRediT authorship contribution statement

Wafae Sellami: Data curation, Formal analysis, Visualization, Writing – original draft. **Abderrazzak Bendidi:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Mohammed Ibriz:** Supervision. **Abdelghani Nabloussi:** Formal analysis, Validation, Writing – review & editing. **Khalid Daoui:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

Many thanks to the technicians and staff of the Douyet experimental station for their helpful assistance during the trial installation and maintenance, monitoring, and data collection.

References

[1] Statistical Databases, 2023. https://www.fao.org/faostat/en/#data/QCL, 07 march.
[2] Minister of agriculture, fisheries, rural development and water and forests. Filière oléagineuse | Ministère de l'agriculture (accessed 07 Jun 2022).
[3] S. Abdelmajid, A. Mukhtar, M.B. Baig, M.R. Reed, Climate change, Agricultural Policy and Food Security in Morocco, Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa: Climate Risks and Resource Scarcity, 2021, pp. 171–196.
[4] H. Tabari, Climate change impact on flood and extreme precipitation increases with water availability, Sci. Rep. 10 (2020), 13768.
[5] T.R. Wheeler, P.Q. Craufurd, R.H. Ellis, J.R. Porter, P.V. Prasad, Temperature variability and the yield of annual crops, Agric. Ecosyst. Environ. 82 (2000) 159–167.
[6] N. Ahmed, I.J. Tetlow, S. Nawaz, A. Iqbal, M. Mubin, M.S. Nawaz ul Rehman, A. Butt, D.A. Lightfoot, M. Maekawa, Effect of high temperature on grain filling period, yield, amylose content and activity of starch biosynthesis enzymes in endosperm of basmati rice, J. Sci. Food Agric. 95 (2015) 2237–2243.
[7] G. Feng, B. Sharratt, F. Young, Soil properties governing soil erosion affected by cropping systems in the US Pacific Northwest, Soil Tillage Res. 111 (2011) 168–174.
[8] P. Tarolli, M. Cavalli, R. Masin, High-resolution morphologic characterization of conservation agriculture, Catena 172 (2019) 846–856.
[9] S.A. Brandt, Zero vs conventional tillage and their effects on crop yield and soil moisture, Can. J. Plant Sci. 72 (1992) 679–688.
[10] A. Kassam, T. Friedrich, R. Derpsch, Global spread of conservation agriculture, Int. J. Environ. Stud. 76 (2019) 29–51.
[11] Official Launch of the Agricultural Campaign 2021-2022 from the Region Rabat Sale Kenitra, 2022. https://www.agriculture.gov.ma/fr/news/official-launch-of-agricultural-campaign-2021-2022-from-rabat-sale-kenitra-region, 28 February.
[12] S. Marinari, R. Mancinelli, E. Campiglia, S. Grego, Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy, Ecol. Indicat. 6 (2006) 701–711.
[13] D. Pandey, M. Agrawal, J.S. Bohra, Effects of conventional tillage and no tillage permutations on extracellular soil enzyme activities and microbial biomass under rice cultivation, Soil Tillage Res. 136 (2014) 51–60.
[14] S. Mangalassery, S.J. Mooney, D.L. Sparkes, W.T. Fraser, S. Sjögersten, Impacts of zero tillage on soil enzyme activities, microbial characteristics and organic matter functional chemistry in temperate soils, Eur. J. Soil Biol. 68 (2015) 9–17.
[15] P.R. Hobbs, Conservation agriculture: what is it and why is it important for future sustainable food production? J. Agric. Sci. 145 (2007) 127.
[16] G.A. Thomas, G.W. Titmarsh, D.M. Freebairn, B.J. Radford, No-tillage and conservation farming practices in grain growing areas of Queensland–a review of 40 years of development, Aust. J. Exp. Agric. 47 (2007) 887–898.
[17] A.W. Lenssen, W.M. Iversen, U.M. Sainju, T.C. Caesar-TonThat, S.L. Blodgett, B. L. Allen, R.G. Evans, Yield, pests, and water use of durum and selected crucifer oilseeds in two-year rotations, Agron. J. 104 (2012) 1295–1304.
[18] X. Yang, L. Zheng, Q. Yang, Z. Wang, S. Cui, Y. Shen, Modelling the effects of conservation tillage on crop water productivity, soil water dynamics and evapotranspiration of a maize-winter wheat-soybean rotation system on the Loess Plateau of China using APSIM, Agric. Syst. 166 (2018) 111–123.
[19] S.F. Christopher, R. Lal, U. Mishra, Regional study of no-till effects on carbon sequestration in the Midwestern United States, Soil Sci. Soc. Am. J. 73 (2009) 207–216.
[20] R. Awale, A. Chatterjee, D. Franzen, Tillage and N-fertilizer influences on selected organic carbon fractions in a North Dakota silty clay soil, Soil Tillage Res. 134 (2013) 213–222.
[21] M.S. Aulakh, J.S. Manchanda, A.K. Garg, S. Kumar, G. Dercon, M.-L. Nguyen, Crop production and nutrient use efficiency of conservation agriculture for soybean–wheat rotation in the Indo-Gangetic Plains of Northwestern India, Soil Tillage Res. 120 (2012) 50–60.
[22] I.W. Nyakudya, L. Stroosnijder, Conservation tillage of rainfed maize in semi-arid Zimbabwe: a review, Soil Tillage Res. 145 (2015) 184–197.
[23] Y. Han, W. Ma, B. Zhou, X. Yang, A. Salah, C. Li, C. Cao, M. Zhan, M. Zhao, Effects of straw-return method for the maize–rice rotation system on soil properties and crop yields, Agronomy 10 (2020) 461.
[24] J. Hirzel, P. Undurraga, L. León, M. Panichini, J. Carrasco, J. González, I. Matus, Different residues affect wheat nutritional composition, J. Soil Sci. Plant Nutr. 20 (2020) 75–82.
[25] A.M. Johnston, D.L. Tanaka, P.R. Miller, S.A. Brandt, D.C. Nielsen, G.P. Lafond, N. R. Riveland, Oilseed crops for semiarid cropping systems in the northern Great Plains, Agron. J. 94 (2002) 231–240.
[26] U.M. Sainju, A.W. Lenssen, B.L. Allen, J.D. Jabro, W.B. Stevens, Stacked crop rotations and cultural practices for canola and flax yield and quality, Agron. J. 112 (2020) 2020–2032.
[27] G.D. Li, M.K. Conyers, G.D. Schwenke, R.C. Hayes, D. Li Liu, A.J. Lowrie, G.J. Poile, A.A. Oates, R.J. Lowrie, Tillage does not increase nitrous oxide emissions under dryland canola (Brassica napus L) in a semiarid environment of south-eastern Australia, Soil Res. 54 (2016) 512–522.
[28] Y. Assefa, P.V. Prasad, C. Foster, Y. Wright, S. Young, P. Bradley, M. Stamm, I. A. Ciampitti, Major management factors determining spring and winter canola yield in North America, Crop Sci. 58 (2018) 1–16.
[29] M.L. Mayer, M.W. Veal, E.E. Godfrey III, M.S. Chinn, Response of canola yields from marginal lands managed with tillage practices, Journal of Agriculture and Food Research 4 (2021), 100133.
[30] J. Holman, S. Maxwell, M. Stamm, K. Martin, Effects of planting date and tillage on winter canola, Crop Manag. 10 (2011) 1–11.
[31] A. Nabloussi, H. Bahri, M. Lakbir, H. Moukane, A. Kajji, M. El Fechtali, Assessment of a set of rapeseed (Brassica napus L) varieties under waterlogging stress at different plant growth stages, OCL 26 (2019) 36.
[32] P. Monneveux, M. Nemmar, Contribution à l'étude de la résistance à la sécheresse chez le blé tendre (Triticum aestivum L) et chez le blé dur (Triticum durum Desf): étude de l'accumulation de la proline au cours du cycle de développement, Agronomie 6 (1986) 583–590.
[33] Michel DuBois, K.A. Gilles, J.K. Hamilton, P.A. Rebers, Fred Smith, Colorimetric method for determination of sugars and related substances, Anal. Chem. 28 (1956) 350–356.
[34] D.I. Donaghy, Zero Tillage crop Production in Manitoba, 1973.
[35] D. Gawęda, M. Haliniarz, The yield and weed infestation of winter oilseed rape (Brassica napus L ssp oleifera Metzg) in two tillage systems, Agriculture 12 (2022) 563.
[36] S. Borstlap, M.H. Entz, Zero-tillage influence on canola, field pea and wheat in a dry subhumid region: agronomic and physiological responses, Can. J. Plant Sci. 74 (1994) 411–420.
[37] Y. Assefa, K. Roozeboom, M. Stamm, Winter canola yield and survival as a function of environment, genetics, and management, Crop Sci. 54 (2014) 2303–2313.
[38] M.R. Alizadeh, A. Allameh, Canola yield and yield components as affected by different tillage practices in paddy fields, International Journal of Agricultural Sciences and Natural Resources 2 (2015) 46–51.
[39] B.D. Soane, B.C. Ball, J. Arvidsson, G. Basch, F. Moreno, J. Roger-Estrade, No-till in northern, western and south-western Europe: a review of problems and opportunities for crop production and the environment, Soil Tillage Res. 118 (2012) 66–87.
[40] C. Thierfelder, M. Mwila, L. Rusinamhodzi, Conservation agriculture in eastern and southern provinces of Zambia: long-term effects on soil quality and maize productivity, Soil Tillage Res. 126 (2013) 246–258.
[41] H. Zhang, J. Berger, C. Herrmann, A. Brown, S. Flottmann, Canola yield and its association with phenological, architectural and physiological traits across the rainfall zones in south-western Australia, Field Crops Res. 258 (2020), 107943.
[42] J.A. Kirkegaard, J.M. Lilley, R.D. Brill, A.H. Ware, C.K. Walela, The critical period for yield and quality determination in canola (Brassica napus L), Field Crops Res. 222 (2018) 180–188.
[43] H. Zhang, S. Flottmann, Source-sink manipulations indicate seed yield in canola is limited by source availability, Eur. J. Agron. 96 (2018) 70–76.
[44] M.J. Morrison, Heat stress during reproduction in summer rape, Can. J. Bot. 71 (1993) 303–308.
[45] J.E. Iboyi, M.J. Mulvaney, K.S. Balkcom, R. Seepaul, M. Bashyal, D. Perondi, R. G. Leon, P. Devkota, I.M. Small, S. George, Tillage system and seeding rate effects on the performance of Brassica carinata, GCB Bioenergy 13 (2021) 600–617.
[46] M.L. Gandía, J.P. Del Monte, J.L. Tenorio, M.I. Santín-Montanyá, The influence of rainfall and tillage on wheat yield parameters and weed population in monoculture versus rotation systems, Sci. Rep. 11 (2021) 1–12.

[47] S. Miersch, A. Gertz, F. Breuer, A. Schierholt, H.C. Becker, Influence of the semi-dwarf growth type on seed yield and agronomic parameters at low and high nitrogen fertilization in winter oilseed rape, Crop Sci. 56 (2016) 1573–1585.

[48] J. Buczek, D. Migut, M. Jańczak-Pieniążek, Effect of soil tillage practice on photosynthesis, grain yield and quality of hybrid winter wheat, Agriculture 11 (2021) 479.

[49] M.F. Saleem, A. Ghaffar, M.H. ur Rahman, M. Imran, R. Iqbal, W. Soufan, S. Danish, R. Datta, K. Rajendran, A. EL Sabagh, Effect of short-term zero tillage and Legume intercrops on soil quality, agronomic and physiological aspects of cotton under arid climate, Land 11 (2022) 289.

[50] H. Habbib, B. Hirel, F. Spicher, F. Dubois, T. Tétu, In winter wheat (Triticum Aestivum L), no-till improves photosynthetic nitrogen and water-use efficiency, Journal of Crop Science and Biotechnology 23 (2020) 39–46.

[51] J.E. Iboyi, M.J. Mulvaney, R.G. Leon, K.S. Balkcom, M. Bashyal, D. Perondi, R. de S. Nóia Júnior, P. Devkota, I.M. Small, Brassica carinata physiological response to land preparation method and seeding rate, J. Crop Improv. (2023) 1–15.

[52] X.D. Jiang, Y. Wang, L.T. Hou, Z.J. Li, X. Wang, Z.H. Guo, Effects of minimum tillage and no-tillage systems on photosynthetic characteristics at late growth stages of winter wheat, Trans CSAE 22 (2006) 66–69.

[53] J.Z. Wu, M. Huang, Y.J. Li, M.C. Chen, Y.Q. Yao, D.Y. Guo, H.X. Huang, Effects of different tillage systems on the photosynthesis functions, grain yield and WUE in winter wheat, Agric. Res. Arid Areas 26 (2008) 17–21.

[54] X. Hou, R. Li, Z. Jia, Q. Han, Rotational tillage improves photosynthesis of winter wheat during reproductive growth stages in a semiarid region, Agron. J. 105 (2013) 215–221.

[55] Y. Rharrabti, D. Villegas, C. Royo, V. Martos-Núñez, L.G. Del Moral, Durum wheat quality in Mediterranean environments: II Influence of climatic variables and relationships between quality parameters, Field Crops Res. 80 (2003) 133–140.

[56] G. Debiase, F. Montemurro, A. Fiore, C. Rotolo, K. Farrag, A. Miccolis, G. Brunetti, Organic amendment and minimum tillage in winter wheat grown in Mediterranean conditions: effects on yield performance, soil fertility and environmental impact, Eur. J. Agron. 75 (2016) 149–157.

[57] M.J. Morrison, P.B.E. Mcvetty, C.F. Shaykewich, The determination and verification of A baseline temperature for the growth of Westar summer rape, Can. J. Plant Sci. 69 (1989) 455–464.

[58] S.A. Brandt, D.I. McGregor, Canola response to growing season climatic conditions, in: Soils and Crops Workshop, 1997.

[59] A. Jan, G. Ahmad, T. Jan, M. Jamal, F. Subhan, Oil yields of canola as affected by N and S levels and methods of application under rainfed conditions, Sarhad J. Agric. 24 (2008) 1.