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Crop Yields under Climate Variability and No-Tillage System in Dry Areas of Morocco

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ABSTRACT

In Morocco, the intensive use of agricultural land coupled with irregular precipitation is a serious threat to the country's food security. Conservation agriculture especially no-tillage (NT) system has shown an important result in the semi-arid regions of Morocco, but its dissemination to other, more humid, agro-ecological zones (precipitation > 350 mm) is still low. For this purpose, a field experiment under NT system has been installed since 2004 in the Zaer Plateau (Central Morocco) to study the adaptation of this system to the irregular rainfall compared to a conventional tillage (CT). Yields (grain and biomass) of crops (wheat and lentil) under NT and CT were analyzed and compared over the years of study. The ANOVA test showed that yields over the seven years were significantly different and that both crop yields under NT system were greater than or equal to those under CT system even though lentil is more vulnerable to extreme climate events under CT and NT systems. Unlike NT, yields under CT were significantly correlated with the rainfall amount received during the crop cycle. This indicates the dependence of CT precipitation, whereas NT is more adaptable to the irregularities of the climate in the study area.

Keywords: no-tillage, crop yield, wheat, lentil, climate variability, dry areas, Morocco.

INTRODUCTION

Agriculture plays an important role in maintaining food security and employment in developing countries [1–3]. It has been the most affected by the impacts of economic and social crises [4–5], which have pushed farmers to use unsustainable agricultural practices. In Morocco, despite a substantial investment in agriculture as a key development priority, the food system is still unsustainable, vulnerable, and marginally human security-oriented. In order to satisfy the growing population, agricultural lands were either mis-managed or intensively used (e.g., mono-cropping, excessive tilling, inadequate input uses, overgrazing, crop residue removal or burning, etc.) [6–7]. In fact, some agricultural practices that are too intensive or not respectful to the environment can be responsible for the degradation of soil, the first factor of production in agriculture. During the agricultural history of Morocco, tillage was central. However, researchers have reported in their studies that deep plowing may contribute in time to a decrease in soil fertility through the depletion of organic matter, which negatively affects the soil properties, [8–10]. This has disturbed the agroecosystem balance and has led to the rapid deterioration of soil quality resulting in the reduction of crop productivity [11].

In addition, the agricultural sector is almost totally dependent on rainfall which varies according to the regions and the agricultural years. Therefore, climate variability is another major scourge that threatens food security [12–13]. Indeed, in recent decades, extreme events (drought or flood) have become more frequent [14–15], and the water deficit will continue according to the climate scenarios predicted for this region [16–17]. According to Montanarella et al., [18], soil erosion and dust storms induced by changes in land use and low soil cover from soil ploughing are among the main causes of land degradation and reduced productivity.

If both factors mentioned above (climate irregularity with the use of inappropriate techniques) are combined in arid and/ or in semi-arid regions of a country where agriculture plays a key economic and social role, this will certainly result in significant impacts on potential agricultural yields and employment opportunities, therefore, threatening sustainability. Faced with such a situation, conservation agricultural practices, particularly a no tillage (NT) system is a promising alternative for adapting production systems to the difficult conditions of the Mediterranean regions and thus ensuring sustainable production [19–20]. Indeed, research has shown that this system makes better use of water, conserves the soil against the different types of erosion by improving its organic matter content and structural stability, and increases agricultural production [21–24]. Because of the NT generated benefits in terms of yield, sustainability, incomes, timeliness of cropping practices, ease of farming and eco-system services the area is of NT systems is approaching 25 thousand hectares in Morocco but 205 million hectares worldwide [25].

Certainly, the main objective of such as system is to ensure the sustainability of agricultural production, but the elimination of tillage may cause a reduction in yield in some areas, especially in wet years [26] or on compacted clay soils [27–28]. However, global experience has shown that with correct management of weeds and crop residue, the crop yields under NT can equal to or exceed those of conventional tillage (CT) [29–31]. In Morocco, the experiments took place in the semi-arid areas of the Chaouia have shown an improvement of soft wheat production under NT system compared to CT system [32]. Certainly, these results are conclusive for cereal-based system in this arid region, but the extension of this system to other agro-ecological zones requires more research in the medium and long term to take into account the environmental conditions, particularly the type of soil and the climate [33–34]. The present research work aims promoting innovative NT systems that can fill the sustainability gaps left by conventional "modern" agriculture while spurring progressive benefits from changes in climate pattern. To contribute to this research effort, a long-term experiment has been installed in the Zaer Plateau (Central Morocco) to study the effect of a NT system on crop yields (cereals and legumes) on a Vertisol under a Mediterranean climate. Indeed, Vertisols occupy an important place in terms of surface in Morocco [35–36] and they reach their production potential only if they are correctly managed [37]. Even though much work has been done on the effect of NT on Vertisol production worldwide [38], these results have been contrasted under Mediterranean climate [39,40]. For their part, Syers et al. [41] assert that there is no single system for managing these soils that is applicable everywhere and that land management, integrating rotation and tillage, must be adjusted according to local conditions.

This research presents the results of the effect of two tillage systems (NT and CT) on biomass and yield of crops (wheat and lentil) during seven years on a Vertisol in the Zaer region (Central Morocco). The objectives of this study are to (i) study the effect of climatic variability on yields (grain and biomass) of the main crops of the region (wheat and lentil) and (ii) analyze the adaptation of no tillage system to Vertisols for sustainable production.

MATERIALS AND METHODS

Site description

The long-term research site is located in the experimental station of the National Institute for Agriculture Research (INRA) in Merchouch (60 km south of Rabat; 33°37' N; 6°43' W). The average annual precipitation and temperature are approximately 400 mm for precipitation and 23 °C for temperature. The monthly averages of the precipitation during the agricultural season (November–June) over a 41-year period (1970–2011) are presented in Table 2. The monthly temperature variation during the seven years (2004–2011) of this research is presented in Figure 1. The experiment was conducted on a plot of 4 ha with a low slope (< 5%). The soil is a Vertisol, rich in clay (> 50% clay), with a basic pH and poor external drainage. The major characteristics of the soil are given in Table 1.

Table 1. Physical and chemical proprieties of the soil in the study area

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	pH (1.1 H_2O)	OM (%)	P_2O_5 (mg/kg)	K_2O (mg/kg)
0–20	50.0	37.0	13.0	7.8	1.9	20.0	323.0
20–40	51.0	38.0	11.0	8.3	1.4	4.0	184.0
40–90	53.0	35.0	12.0	8.6	1.3	1.0	145.0

Note: OM – organic matter, P_2O_5 – available phosphorus, K_2O – exchangeable potassium.

Table 2. Monthly average of rainfall (in mm) received between 2004-2011 and 1970–2011

Period	2004–2005	2005–2006	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011	Average (2004–2011)	Average (1970–2011)
November	16	75	10	68	83	60	170	69	53
December	67	28	20	15	85	154	125	71	71
January	9	139	18	53	97	225	60	86	61
February	32	83	29	45	106	91	42	63	50
March	29	38	21	13	26	116	56	43	55
April	2	17	43	92	8	25	56	35	47
May	4	15	18	45	1	20	27	17	19
June	2	12	0	0	2	14	10	6	4
Total (CGP)	161	407	159	331	408	705	546	390	360
VGP	124	325	77	181	371	530	397	289	242
RMP	35	70	82	150	35	161	139	95	122
Deviation/CGP	-229	17	-231	-59	18	315	156	--	--

Note: VGP – vegetative growing period (November to February), RMP – reproduction & maturity period (March to May), CGP – crop growth period (November to June), deviation (CGP), the difference between total rainfall in (CGP) per year and average total rainfall in (CGP) in (2004-2011).

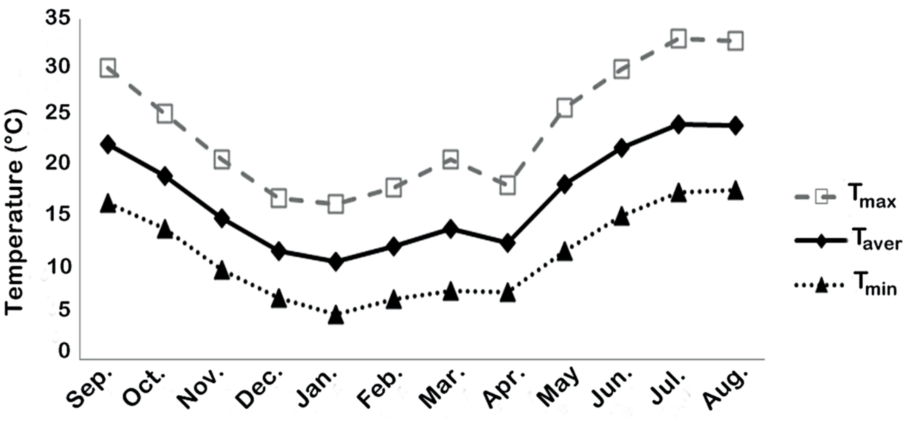

Figure 1. Monthly variation of average, maximum and minimum temperature in the study area: T_{max} – maximum temperature; T_{aver} – average temperature; T_{min} – minimum temperature

Experimental design and management

The experimental design consists of a comparison of two tillage systems: no tillage and conventional tillage, practiced from 2004 to 2011 (7 years study) on two adjacent plots of 100 m length and 50 m width each. The CT system adopted is the one practiced by farmers in the region and consists of a deep plowing of the soil (plowing up to 30 cm deep) during the summer with a "stubble plow" allowing the burial of harvest residues, followed in early autumn by a second plowing (10–15 cm) with a chisel and two passes with a disc implement to prepare the seedbed. In contrast to the NT system, there are no tillage or soil preparation operations. Hence, the most important requirements in terms of mechanization in NT systems, are precise seeding, banding fertilizers and adequate harvest.

In fact, the seeder used places the seeds and fertilizers (at approximately 5 cm depth) without turning or major disturbance of the soil. For reason of homogenization, both plots were left in fallow for two years before the installation of the trial. Since September 2004, the plots receive the same soil and crop management practices (tillage, rotation, variety, seeding dose, and fertilizer dose and type).

The biennial rotation adopted is soft wheat-lentil. Winter wheat (*Triticum aestivum* L. cv Arrihane was sown 50 mm deep at a seed rate of 0.14 t ha^{-1} and received 0.15 t ha^{-1} of complex type fertilizer (14-28-14 i.e., 14% nitrogen, 28% phosphorus and 14% potassium). Depending on each season's climate condition, sowing dates varied from 20 November to 5 December. Like many leguminous crops, lentil (*Lens culinaris* L. cv Bakria) plays a key role in crop rotation due to their ability to fix nitrogen. It was seeded using the No-till wheat drills at a rate of 0.04 t ha^{-1} at spacing of 0.50 m. The fertilizer dose was 0.10 t ha^{-1} of complex type (14-28-14).

At harvest, at least 30 % of the crop residues were maintained on the soil surface under NT system. All phases (rotation-year) of each rotation were present each year and each treatment was cycled on its assigned plot. Under CT, weeds are controlled though soil inversion before seeding while under NT system, chemical weed control is the only option. Thus, for wheat, an herbicide based on Flumetsulam was used at a dose of 50 ml ha^{-1} before sowing. For lentil, weeds were burned using 3 l ha^{-1} of Paraquat before sowing. In mid-season, NT and CT systems received the same treatment doses with 1 l ha^{-1} of herbicide, for lentil, based on Fluazifop-P-butyl at the beginning of February of each season and for wheat, 50 ml ha^{-1} of herbicide based on Flumetsulam was applied in March of each year. For controlling Hussian fly, Furadan 5G was used at the time of sowing of wheat at a rate of 25 kg ha^{-1}. This is knowing that the variety of Arrihane has resistance to this insect. To control foliar diseases of cereals, a preventive fungal treatment based on Propiconazole was used at a dose of 0.5 l ha^{-1}.

Sampling and measurements

Climatic parameters

Precipitation was measured with a standard rain gauge and data were collected daily between 1970 and 2011 at two meteorological stations installed at the INRA experimental farm. Daily precipitations averages were transformed into monthly averages to facilitate their interpretation. The inter-annual monthly precipitation averages over the trial period (2004–2011), compared to the 1970–2011 period, are given in Table 2.

Crop yields

In this study, the focus was on grain and straw yields. At harvest, wheat grain was hand sampled from five quadrats of 1 m^2 taken randomly within each plot to determine grain yield, reported at 130 $g \cdot kg^{-1}$ moisture concentration. For lentil, five random lines of 10 m each were taken from each plot (NT and CT). Straw and grain yields were measured from these collected samples.

Statistical analysis

Data were analyzed by ANOVA for all years. For each year, a test comparison of means was used to separate between NT and CT treatments with the (t-Student) test.

RESULTS AND DISCUSSION

Climatic conditions

The study area, marked by a Mediterranean climate, often has significant climate variability [15]. As shown in Table 2, during the seven years of experimentation, the average cumulative precipitation during the growing season (November to June) was 390 mm while over the 41 years (1970–2011), the average cumulative precipitation during the growing season was 360 mm. This shows that the average cumulative rainfall during the agricultural season was higher during the last seven years than during the last four decades. Indeed, during the period of this study, the agricultural seasons have been pronouncedly different. Of the seven years observed, three years were relatively less wet (2004–2005, 2006–2007 and 2007–2008) compared to the last two seasons (2009 to 2011) which were wet while the other two seasons (2005–2006 and 2008–2009) had precipitation more or less near the average observed in the region over the 41 years (360 mm) (Table 2).

The average total precipitation received during the vegetative growing period (VGP) between November and February, which is about 289 mm over the seven years, constitutes 74% of

Table 3. Parameter of variance analysis of yields (grain and biomass) of wheat and lentil crops according to years (2004–2011) and type of tillage (NT and CT)

Parameters	Deviation square				
	Parameter	Wheat yield		Lentil yield	
Source of variation	Df	Grain	Biomass	Grain	Biomass
Year	6	16.096*	31.703*	2.589*	3.631*
Tillage	1	1.404*	7.134*	0.011*	0.216*
Year * tillage	6	0.178*	0.384*	0.100	0.230*
Error	28	0.040*	0.091*	0.032*	0.020*

Note: (*) indicates the existence of a significant effect ($P < 0.05$) by the F test.

the total rainfall received during the agricultural season. As for the reproduction and maturity period (RMP), the average rainfall received is 95 mm and constitutes 24% of the average total rainfall recorded during the entire crop growth cycle (CGP) (Table 2).

The climate variation of the region is clearly observed during the 2006–2007 season with a low rainfall record of 159 mm and during 2009–2010 with a maximum rainfall amount of 705 mm. In fact, the region has never recorded such high level of rainfall according the 41 years of rainfall data. The same variation in rainfall is present during the period of plant development (VGP), where in the year 2006–2007, the rainfall received was low (87 mm) while in the wet year (2009–2010), it was about 530 mm. During this same year, 161 mm of rain was recorded in the period of grain maturity (RMP), whereas in the dry year (2006–2007) only 72 mm of rain was received (Table 2). From this analysis, it can be concluded that rainfall variability is considerable and that crop yields are significantly affected by the interactions of tillage practices and annual rainfall observed between 2004 and 2011 (Table 3).

Wheat

Grain yields

Wheat production is particularly vulnerable to the impacts of climate variability and change, given that it is largely rain-fed and also due to the fact that wheat productivity is still low and unstable. As shown in Figure 2, the variation in rainfall received over the seven years had a remarkable effect on the crop yield variation. Indeed, in the drier year (2006–2007), yield was low and no significant difference was observed between the two tillage practices. In contrast, in a relatively less dry year (2007–2008), yield under NT system was significantly higher than under CT system.

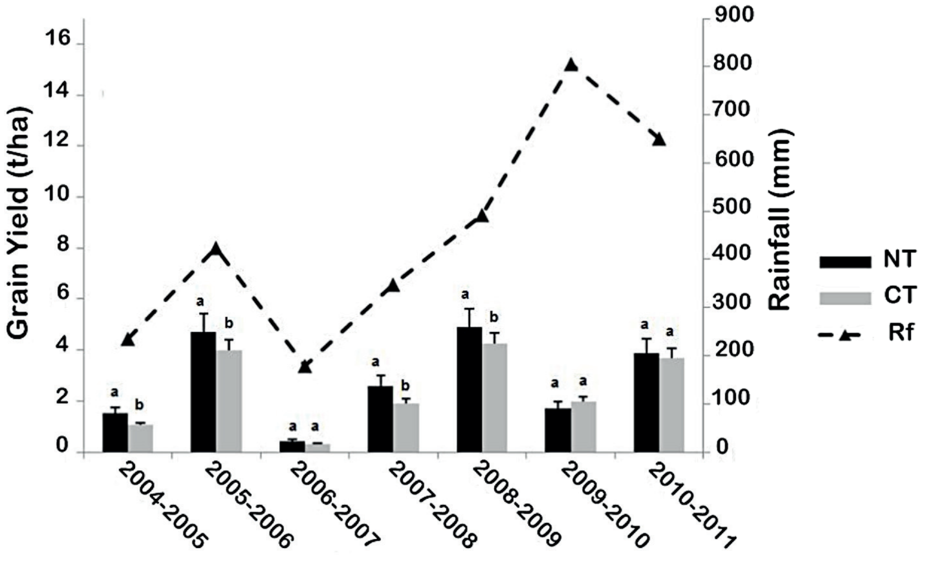

Figure 2. Tillage effect on wheat grain yield in relation to total rainfall received during the growing season (November–May): NT – no tillage; CT – conventional tillage; Rf – rainfall

The same was observed in average years (2005–2006 and 2008–2009). On the contrary, in wet years (2009–2010 and 2010–2011), no significant difference was observed between the yields under NT and CT systems.

This last situation could be explained by the fine texture of the Vertisol (≥ 50 % clay) leading to low drainage which decreasing the grain yield during the wet years. Indeed, the water excess favors the rise of weeds and the infestation of the crop by cryptogamic diseases, which affects the maturity of the grains and consequently reduces the yield [42]. This is in line with Wang et al. [43], who reported in their study that soil texture is one of the main factors influencing crop yield in NT trials. To avoid the negative effect of hydromorphic condition on wheat production in Vertisols, farmers try to improve the soil drainage in wet years [44].

In general, wheat grain yields under NT system were equal to or greater than those under CT system regardless of rainfall conditions during the seven-year study. Therefore, the wheat crop did not yield well under either NT and CT systems in wet years. In addition, a minimum cumulative rainfall of 190 mm is required to ensure wheat grain production [45]. However, the wheat crop allowed a grain yield in dry years (2004–05 and 2006–07), which shows that the residual water in depth was used and more consistently under NT. In the similar line, grain yield under NT with residue retention, increased in regions with precipitation < 600 mm and decreased in regions with ≥ 600 mm [43]. In semi-arid regions, Bahri et al. [46], Ruis et al. [47], showed that NT system guaranteed superior grain yield especially when water stress during the crop cycle was high. However, Seddaiu et al. [48] did not find any substantial benefits to wheat grain yield under NT when compared to CT or minimum tillage systems, and this situation was explained by both, soil type (Calcaric Gleyic Cambisols) and climat conditions in the experimental site (mean annual rainfall = 820 mm; air mean temperature = 15 °C).

Straw production

The same effect of precipitation on wheat grain yields is observed on straw yield (biomass). Indeed, with the exception of the very wet year (2009–2010) when yields under NT and CT systems were identical, the Vertisol under NT system had significantly more biomass than under CT system (Figure 3). In addition, in years (2004–2005 and 2006–07), which were dry years (less than 200 mm compared to the average), the biomass under NT was 0.5 t ha^{-1} higher than under CT. Biomass yield was also found in favor of NT in an arid region [49].

The results obtained over seven years on the effect of NT on wheat production (grain and straw) compared to CT are in agreement with several research works [26, 32, 39, 50–52]. In the same sense, Fernández-Ugalde et al. [53], recommend to farmers in the Mediterranean semi-arid region, to consider adopting NT techniques to reduce the effect of rainfall irregularity and to

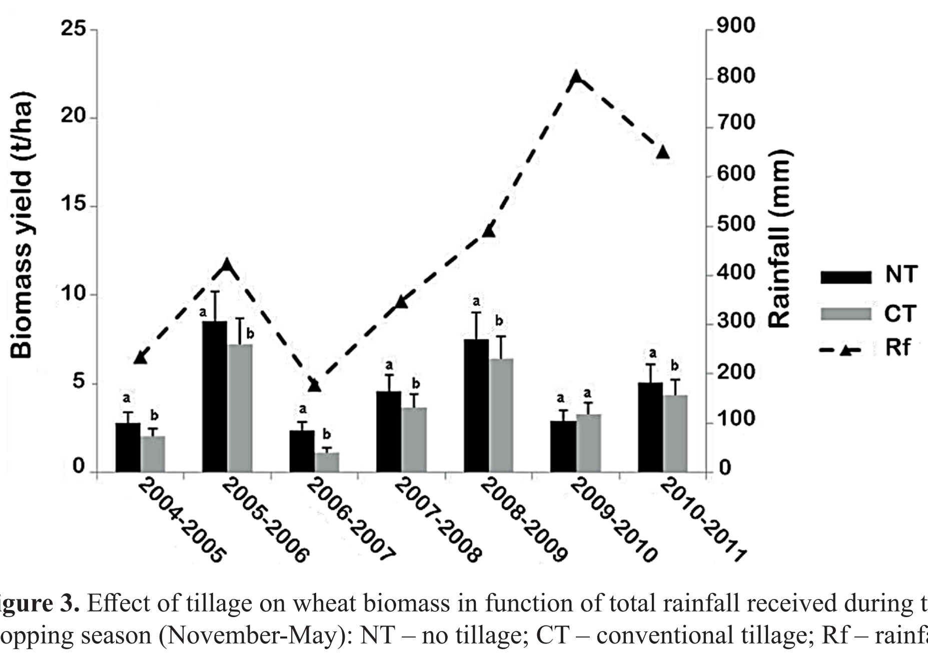

Figure 3. Effect of tillage on wheat biomass in function of total rainfall received during the cropping season (November-May): NT – no tillage; CT – conventional tillage; Rf – rainfall

increase the yield stability. Generally, the positive effect of NT on wheat yield is probably due to straw mulch accumulated under NT plots, which minimizes soil evaporation and enhances soil organic matter in the upper soil layers. Indeed, the improvement in this last main soil parameter, can lead to the improvement in crop nutrient response especially in terms of nitrogen [54–55]. In the same site experiment (Merchouch), Moussadek et al., and Laghrour et al. [21, 56] showed that organic matter and nitrogen in vertisol were significantly higher under NT compared to CT. Moreover, soil evaporation is combined with enhanced soil water availability [50]. NT with rotation can be another reason for wheat yield improvement in the dry conditions, while, the inverse finding (in favor of CT) was observed under a mono-cropping system [48].

Lentil

Grain yield

From Figure 4, there is considerable variation in grain yields in relation to the received precipitations. Indeed, yields varied from 1.7 t ha^{-1} in an average year to 0.1 t ha^{-1} in a dry year. However, during the exceptionally wet year (2009–2010), no crop was obtained under both systems (NT and CT). This can be explained by the excess of water recorded in March 2010, which coincided with the grain filling period. This sensitively affected the yield of lentil which is a crop sensitive to hydromorphic conditions especially in clay soils [57]. Similarly, during the dry season (2006–2007), the accentuated hydric deficit during the vegetative period (VGP) resulted in reduced yields under both tillage systems, although the reductions was slightly less under NT. In the other study years, yield was significantly higher under no tillage or equal to that obtained under conventional tillage. Previous studies supported our findings indicating the increase in lentil yield under NT vs CT in dry climates [58–59]. Giambalvo et al., who studied other grain legume, showed that NT system was able to improve faba bean grain yield by 31% compared to CT, and this advantage was observed under the scarce rainfall (< 400 mm) [60].

Straw production

According to Figure 5, it can be seen that, except for the last two wet years (2009–2010 and 2010–2011), biomass production was significantly higher under NT than under CT. In wet years, with the excess of water, there was an invasion of weeds in both tillage systems, which seriously affected biomass yields.

These results are concordant with previous finding which evidenced that lentil yields (grain and biomass) under NT are higher than under CT, especially in semi-arid Mediterranean environments [61–62]. As discussed above in the wheat yield section, the residue retention under NT system decreases water evaporation and thus increase soil water retention which improved the yield production. For these reasons the adoption

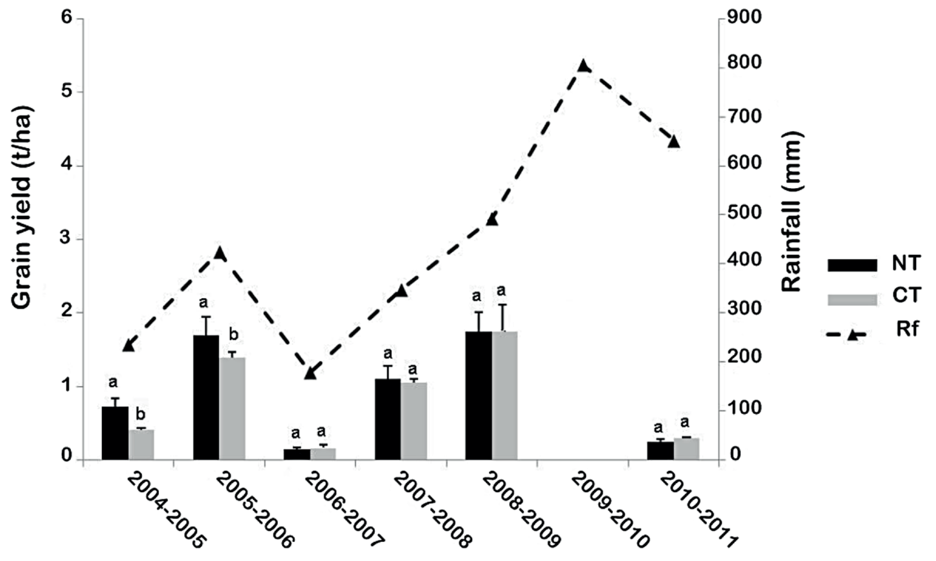

Figure 4. Effect of tillage system on grain yield of lentil in function of total rainfall received during the cropping season (November-May): NT – no tillage; CT – conventional tillage; Rf – rainfall

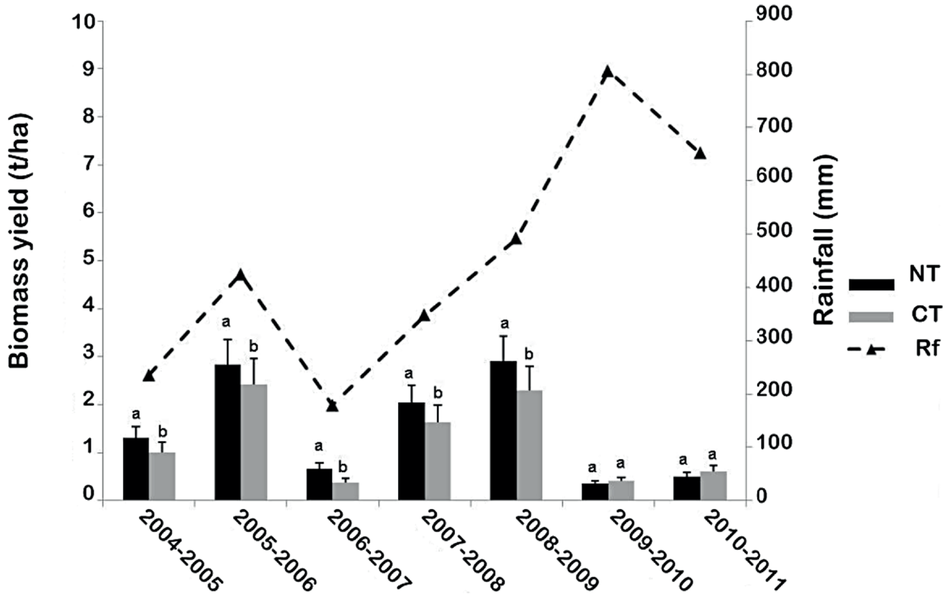

Figure 5. Effect of tillage systems on lentil biomass in function of total rainfall during the cropping season (November–May): NT – no tillage; CT – conventional tillage; Rf – rainfall

Table 4. Regression coefficients between yields (grain and biomass) of crops (wheat and lentil) and total rainfall received during the crop growing period (CGP), vegetative growing period (VGP) and reproduction and maturity period (RMP) under no-tillage (NT) system and conventional tillage (CT) system

Crops	System	Grain Yield			Biomass yield		
		CGP	VGP	RMP	CGP	VGP	RMP
Wheat	NT	0.376	0.636	0.007	0.661	0.668	0.001
	CT	0.431	0.895*	0.005	0.653	0.885*	0.008
Lentil	NT	0.112	0.483	0.107	0.134	0.382	0.008
	CT	0.397	0.692*	0.130	0.351	0.581	0.017

Note: (*) Indicates the presence of a significant correlation (Pearson coefficient).

of NT is an appropriate strategy for lentil yield in the Mediterranean climate.

Grain yield-rainfall relationship

The change from tillage-based systems to NT systems implies a different crop behavior and performances vis-à-vis climate and soil attributes variability. In this section, the emphasis is on rainfall variation even though it was also found that soil health has improved under NT systems [21,56]. Table 4 shows the linear regression coefficients between crop yields (wheat and lentil) and rainfall received during the entire growing season (CGP), during the vegetative growing period (VGP), and during the reproduction and maturity period (RMP). This table shows that the grain yield of crops (wheat and lentil) is weakly correlated with the cumulative rainfall received during the growing cycle (CGP). The highest values of correlation obtained between rainfall and yields were observed for the vegetative growing period (0.895 and 0.692 for grain yields of wheat and lentil respectively; 0.885 and 0.581 for straw yields of wheat and lentil respectively). This shows that yields in semi-arid areas are affected more by the distribution of rainfall during the growing season rather than by its total amount [62]. Our results are in the line with the findings of Sarker et al. [63] and Tafoughalti et al. [64] who showed that climate change is impacting lentil and wheat yields respectively. However, all the highest values mentioned above were obtained under CT system and this mean that this management system is more dependent on rainfall for crop production than under NT. This proves also that under CT, yields are more dependent on precipitation at the beginning of the vegetative cycle, unlike in NT. Indeed, the presence of mulch on the surface reduces this dependence by conserving water against evaporation and improving its infiltration to make it available to the plant during the dry periods of the cycle [39].

CONCLUSIONS

Reducing soil disturbance by implementing no-tillage practices was found to enhance wheat and lentil productivity vis-à-vis rainfall variability in central Morocco. Such studies are important to accelerate the shift to more regenerative agriculture based on reducing harms to soils and crops through tillage management and intensification [54]. In special situation of excess rainfall, lentil crop was more vulnerable in condition of soils of limited drainage and its biomass was reduced under NT compared to CT. This calls into question the choice of this crop as a rotation with wheat in wet years on Vertisols under conservation agriculture. In addition, weed control seem to be another problem associated with lentil crop in NT systems. In this regard, the focus should be on managing weed populations and flora with integrated options rather than eliminating weeds solely using herbicides [65].

From the present research, NT can be used by Moroccan farmers to increase yields while also making crops more resilient to changing climatic conditions. In fact, it was reconfirmed that NT can reduce drought effects through better water storage and availability during crop growing season in wheat-based systems. Operational benefit from NT is the flexibility for the implementation of field crop management that allows timely seeding and input application, despite unfavorable field conditions that do prevent such operations in conventional tillage systems (e.g., wet or hard soil at planting time). In other terms, knowing that wet years are statistically less and less frequent in the region and that climate scenarios predict more aridity in this environment, it can concluded that with its interlinked principles, NT systems is a sustainable alternative and promising for reducing the vulnerability of the cereal and legume crops to climatic variations and for producing in a sustainable manner on these Mediterranean Vertisols. The NT principles of eliminating tillage, maintaining mulch cover and diversifying cropping systems are essential for proper management of vertisols while underpinning the biochemical and physical processes and facilitating crop growth and development.

In Morocco, farmers and growers are faced with rising prices of energy and inputs (seeds, fertilizers, pesticides and machinery) and NT systems may be an option for reducing costs due to elimination of tillage and seedbed preparation, optimized seed and fertilizer uses, more timely sowing and reduced reliance on labor and energy, integrated pest management with improved crop health and soil quality overtime. By assessing and capitalizing on this potential from NT, food security or sovereignty can be achieved by 2030 as planned by the newly launched agricultural policy called Generation Green. The road map for upscaling and large adoption of a wide range of farmers in Central Morocco will certainly added to successful experiences discussed by Kassam et al. [66].

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