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Yield and Energy Requirement of Durum Wheat under No-Tillage and Conventional Tillage in the Mediterranean Climate

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ABSTRACT

A key principle of no-tillage (NT) system is the retention of crop residues on the soil surface to preserve soil water for crop growth. In response to the negative impact of soil degradation processes under conventional tillage (CT) systems that are based on soil tillage, NT systems without tillage practices and with protective cover of crop residue are being developed in many parts of the world. Apart from the positive effects on soil conservation and sustained land productivity, another major impact of NT is decreasing labor costs, generally leading to higher income and a better standard of living for the farmers. However NT is a successful system especially in the South of America, but the impacts of this system in the Mediterranean climate especially in the south of France is less well known; so that this study has been carried out within the scope of a European project. Durum wheat was sown for two years under two tillage treatments i.e. CT and NT. Time requirement and fuel consumption in these two systems were measured. The results show that the crop production is higher in CT system, while work duration and energy requirement is lower in NT system.

Key Words: No-tillage, conventional tillage, durum wheat, energy requirement.

INTRODUCTION

NT system is becoming increasingly attractive to farmers because it clearly reduces production costs relative to CT systems. NT provides feasible soil management with fewer disturbances to soil agroecosystems compared to CT. The main objective of soil cultivation, i.e. the proper sowing and raising of crops, can be achieved at lower costs and labor hours. Classical aim of tillage systems in agriculture are to create good seed-to-soil contact and an appropriate root environment in topsoil; to provide optimal conditions for subsequent crop with respect to water, air, and heat budget; and to control weed infestation. Under practical farm conditions these goals are too often not met, and structural degradation can be observed (El Titi, 2003). The improved soil organic matter content in NT soils categorize this system as supporting more sustainable agricultural resources that restrict environmental as well as global pollution risk.

Substitution of CT system by various types of conservation tillage in USA recently reached at 41% of total arable land (45.64×10^6 ha). Within mentioned land area NT reached even at 23% or 24.96×10^6 ha (Kosutic *et al.*, 2005). Nowadays conservation tillage occupies 14% of arable land of Spain in which 15% or 300×10^3 ha is under NT. In Germany, the distribution of conservation tillage has considerably increased in the past 10 years. Unfortunately in Germany no comprehensive statistics exist on the distribution of conservation tillage, but presumably approximately 20-25% arable land is under conservation tillage (2.38×10^6 ha) in which 15% is under NT. In France, the estimation is that the surface under conservation agriculture techniques is 17% of total arable land (3×10^6 ha) with an increase of 1 million ha in comparison with the situation in 1999. The surface under NT has increased from 50×10^3 to 150×10^3 ha (0.3% of total arable land) in the same period (ECAF).

Different authors (Koller, 1989; Lal, 1989; Blevins and Frye, 1993; Fischer *et al.*, 2002; Bueno *et al.*, 2006) assessed and confirmed ecological and economical advantages of direct seeding. Despite of the potential benefits of this system from an environmental and economical point of view and the possibility of its application in most of the European country; the evolution of conservation agriculture has been slower in European Union than in other parts of the world, especially when talking about NT.

NT has considerable potential for stabilizing production in semiarid zones, but can have contrasting consequences on water conservation and yield. Lal *et al.* (1978) and Osuji (1984) demonstrated positive effects, whereas Chopart and Kone (1985) and Wilhelm *et al.* (1987) found negative effects. NT systems are characterized by high levels of previous crop residues on soil surface. The presence of residues can conserve soil moisture and decrease evaporation. But sometimes residues hinder correct seed placement and appropriate row closure in NT. The presence of residue may delay plant emergence and reduce crop yield mainly because of cooler soil temperatures. Delayed crop emergence and reduced plant population are problems sometimes associated with durum wheat under NT. Poor crop establishment, low plant populations, and delayed early plant growth due to higher mechanical resistance of soil were the primary cause of low durum wheat yields on NT.

The long term effects of CT and NT, under Mediterranean conditions have hardly been studied. Furthermore there is little information in the literature concerning the effects of tillage systems on durum wheat in

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Mediterranean conditions. Yield responses to tillage systems can differ widely with respect to soil type, crop species, precipitation, and region. In this region most rain falls during autumn and winter, and so that water deficit emerges in the spring resulting in a moderate stress for wheat around anthesis, which increases in severity throughout grain filling (Edmeades *et al.*, 1989). In the Mediterranean region, low and erratic distributions of rainfall explain as much as 75% of the variation in wheat yield (Blum and Pnuel, 1990).

As cited by Garcia del Moral *et al.* (2003), Development of floral primordia takes place during the phase of rapid vegetative growth; thus, competition for limiting resources between vegetative and floral organs may occur (Miralles *et al.*, 2000). Later, grain filling is maintained by a high contribution from assimilation before and immediately after anthesis and remobilization of vegetative reserves during kernels growth (Bidinger *et al.*, 1977; Royo *et al.*, 1999). The growth period most sensitive to drought stress, with respect to grain yield, is from double ridge to anthesis due its negative impact on spikelet number and kernels per spike (Shpiler and Blum, 1991). In the same way, weather deficit around anthesis may lead to a loss in yield by reducing spike and spikelet number and the fertility of surviving spikelets (Giunta *et al.*, 1993). In addition, drought stress from anthesis to maturity, especially if accompanied by high temperatures, hastens leaf senescence, reduces the duration and rate of grain filling, and hence reduces mean kernel weight (Royo *et al.*, 2000).

NT has been widely used in the last decades as an attractive alternative to CT because of their potential to reduce production costs. Besides lower operation costs, NT can save significantly the time with seedbed preparation compared with CT. However, yield variably with NT still remains a major concern among farmers.

Acceptance of NT for durum wheat depends more on its profitability rather than gain yield alone. Profitability for durum wheat depends on income (grain yield × price for grain) and total production cost. In general, greater economic returns and lower production cost of reduced tillage systems result in reduced energy and operator time requirements compared with CT (Smart and Bradford, 1999). The economic return for NT may vary considerably with many factors such as soil characteristics, management practices, crop rotation, and labor inputs compared with conventional or other conservation tillage systems (Lithourgidis *et al.*, 2005). Karunatilake *et al.* (2000) reported that long-term use of reduced tillage systems was more economic than CT on well structured clay loam soils. Smart and Branford (1999) found in a 4-year tillage study that conservation tillage systems (reduced and NT) had greater economic returns compared with CT. Moving away from plowing could lead us to a reduction of approximately 50 to 70% in power and energy use. Depending on soil type and the exact method of cultivating stubble and seeding operations, corresponding fuel saving would range from 20 to 50 $l.ha^{-1}$ (El Titi, 2003).

The objective of this research was to determine the effects of NT and CT systems on durum wheat yield, and to compare the energy and time requirement of these two tillage systems.

MATERIALS AND METHODS

An experimental study under irrigation condition has been carried out at Lavalette experimental site of the Cemagref Institute (43° 40’ N, 3° 50’ E, altitude 30 m) in Montpellier in the South of France, located 15 km north of Mediterranean Sea. The average annual rainfall is 823 mm.year-1 (a 13-year average). Evapotranspiration calculated by Penman equation (1948) exceeds rainfall throughout the year under this Mediterranean climate (910 $mm.year^{-1}$). Those climate data were monitored at a weather station situated in the experimental station.

The tillage treatments consist of: conventional tillage (CT) and no-tillage (NT). For NT there were two plots, NT1 and NT2. According to the soil Survey Staff of the United States Department of Agriculture, i.e. USDA soil classification (Hillel, 1980 and Bybordi, 2001), CT and NT1 belong to the Loam; whereas NT2 belongs to the sandy clay loam. The values of physical and chemical properties of the soil were given in Table 1. In CT plots plough, disc harrow, harrow, and seeder were used; whereas in NT plots a specific seeder namely SEMEATO was employed.

Table 1. Soil physical and chemical properties at the Lavalette Agricultural Research Station, Montpellier, France.

Plot	Clay (%)	Silt (%)	Sand (%)	Texture (USDA) (0-120 cm)	Organic matter (%)	Organic carbon (%)	N total (%)	C/N
CT	18	47	35	loam	1.55	0.91	0.07	12.3
NT1	17	39	44	loam	1.76	1.02	0.09	11.4
NT2	25	44	31	sandy clay loam	2.05	1.19	0.11	11.2

Besides texture, other soil properties presented here are for 0-30 cm.

The crop rotation before 2004/2005 growing season was: (2000/2001) oat - corn, (2001/2002) oat -corn in CT and NT1 and oat - sunflower in NT2, (2002/2003) wheat - sorghum, (2003/2004) mixed of oat and vetch – sorghum. Each season, the first crop i.e. cover crop which was used to produce mulch, was destroyed approximately 2 weeks before sowing the second crop i.e. main crop, by using glyphosat.

After a 4-year study on summer crops, durum wheat was sown for 2 crop seasons i.e. 2004/2005 and 2005/2006. For these two seasons there was not any cover crop, but there were enough residues on the soil surface. At the beginning of 2004/2005 season, there was 2.8 and 1.5 $t.ha^{-1}$ in NT1 and NT2, respectively. For the 2005/2006 season, there was 1.12 and 2.14 $t.ha^{-1}$ in NT1 and NT2, respectively.

The first growing season

In CT plots, primary tillage for durum wheat with disc harrow was done to chop and bury the residues at the end of September 2004. Secondary tillage with plough was performed 4 days later; Depth of the tillage was in average 25cm. By using a harrow, seedbed was prepared and sowing of durum wheat was performed by a seeder. Durum wheat (*Triticum turgidum L. var. durum*) was sown in CT on 17 November 2004. In NT plots sowing was performed with a specific seeder, namely Semeato in 30 November 2004. All agronomic practices were kept normal for all treatments.

Durum wheat was hand harvested in 28 June for yield and yield component from four 1-m rows per plot five times. Samples were dried and threshed. Grain yields were calculated after threshing. After harvesting, the experiment area was left completely fallow over summer for 3-4 months.

The second growing season

In CT plots, primary tillage for durum wheat with disc harrow was done to chop and bury the residues at the end of July 2005. Secondary tillage with plough was performed at the beginning of October; Depth of the tillage was in average 25cm. By using a harrow, seedbed was prepared and sowing of durum wheat was performed by using a seeder. Durum wheat (*Triticum turgidum L. var. durum*) was sown in CT on 23 November 2004. In NT plots sowing was performed with a specific seeder, namely Semeato in 29 November 2004. Durum wheat harvesting was at the end of June.

Farm scale equipments were fixed and repeated on the same plot during the experiment period. Time requirement for each operation was calculated. The energy requirement for each tillage system was determined by measuring the tractor fuel consumption applying volumetric system. Energy equivalent of 38.7 $MJ.L^{-1}$ according to Cervinka (1980) was taken for energy calculation. A HI 955 XL tractor with 95 horse power was used in this experiment. There was not any considerable slope in all plots. Bulk density of soil in 0-25 cm was 1.57, 1.65, and 1.7 in CT, NT1, and NT2, respectively.

Statistical evaluation of this experiment was performed by the analysis of variance (ANOVA). The Duncan's test was employed to compare the mean results, after a significant variation had been highlighted by ANOVA. The differences had been considered as significant if $P<0.05$.

RESULTS AND DISCUSSION

Weather conditions

Yield of Mediterranean crops is widely variable due to high seasonal variability of rainfall. There was a great variation in the total and monthly distribution of precipitation between two cropping seasons and the 13-year average. Total rainfall over the cropping season decreases 53 and 38% in 2004/2005 and 2005/2006, respectively, in comparison with the 13-year average. Rainfall during the pre- and post-anthesis growth period was lower too. Mean monthly temperature for the growing season was near the long-term average. However for

2004/2005, in the middle of the season, the air temperature decreases which can delay anthesis; and in June, air temperature was higher than the long-term average. In 2005/2006, the air temperature was lower than the long-term average which can delay and reduce crop emergence especially in NT where the soil temperature is lower than CT (Khaledian *et al.*, 2006a).

Table 2. Monthly rainfall, Penman evapotranspiration, and mean air temperature for two season compared with a 13-year average at Lavalette.

Month	**Rainfall (mm)**			**Penman Evapotranspiration (mm)**			**Mean air temperature °C**		
	2004-2005	2005-2006	13-year average	2004-2005	2005-2006	13-year average	2004-2005	2005-2006	13-year average
November	14	41	92	17	19	18	10	10	10
December	58	4	103	12	8	9	8	4	8
January	2	194	72	18	11	12	6	6	7
February	20	5	46	32	25	27	5	6	8
March	14	23	36	57	58	57	9	10	11
April	31	6	65	92	97	86	13	14	13
May	43	16	51	134	137	122	17	18	17
June	55	21	36	168	169	153	23	21	21
Total	236	311	501	530	524	476			
S. D.*	-265	-190		54	48				

* Deviation from 13-year average.

Grain yield

The amount of wheat grain yield and response to the tillage systems varied depending on the season. In the first growing season, grain yield was significantly higher in CT while no significant effect of no-tillage on grain yield was evident in both NT1 and NT2.

In the second year, grain yield was lower in all treatments as compared with the first season. In CT, grain yield was significantly higher (Table 3). Similar to the first year of the experiment, no significant impact of soil texture was found in NT treatments.

Table 3. Average durum wheat yield of two growing seasons.

Tillage system	**Durum wheat 2004/2005 Mg.ha^{-1}**	**Durum wheat 2005/2006 Mg.ha^{-1}**
Conventional tillage (CT)	6.65a	5.94a
No-tillage plot 1 (NT1)	3.06b	2.72b
No-tillage plot 2 (NT2)	3.44b	2.75b

Data within the same column followed by the same letter are not significantly different at the probability level $P<0.05$.

The emerged plant number was significantly higher in CT than NT (results not showed here). The unfavorable effects of residues prevent proper seed placement and emergence. Better plant emergence in CT translated into higher grain yield. Lower yield under NT may have been associated with the development of cereal leaf beetle (Oulema melanopus L.); this pest can cause senescence during grain filling stage. The lower grain yield with NT compared with CT might have been partly due to greater water loss or lower root development with NT (Khaledian *et al.*, 2006b).

Energy and time requirement

Table 4 shows fuel consumption, energy requirement, and the work duration of machinery used for crop establishment in each treatment. According to data presented in this table, it is evident that CT system was the greatest fuel and energy consumer. The greatest part of the energy, almost 45% or 696.6 MJ.ha^{-1} spent to plow, while NT system required only 270.9 MJ.ha^{-1}. In comparing these data to other sources, wide variations can be expected due to soil types, field conditions, working depth, etc.

NT involved time saving of 87% for crop establishment, as compared to CT. The time required per hectare was reduced from 7.55 h to 1 h. Work rate is better in NT system. That parameter can be interesting when we have not lots of time to prepare the soil for sowing or in some cases one or more tractors and one or more workers can be saved.

Table 4. Energy and time requirement of two tillage methods to prepare the soil for sowing durum wheat (two years average).

Tillage	Fuel consumption $L.ha^{-1}$	Energy requirement $MJ.ha^{-1}$	Work duration H	Work rate $ha.h^{-1}$
Conventional tillage (CT)				
Plough	18	696.6	2.55	0.39
Disc-harrow	8	309.6	1	1
Harrow	8	309.6	3	0.33
Seeder	6	232.2	1	1
Total	40	1548	7.55	
No-tillage (NT)				
No-tillage seeder	7	270.9	1	1

In table 5 total energy and total work duration in both tillage systems over the season were shown. According to data presented for both seasons, it is evident that CT system was the greatest fuel and energy consumer. CT required 2631.6 and 2476.8 $MJ.ha^{-1}$ for the first and second season, respectively. The maximum energy requirement in NT is 1431.9 $MJ.ha^{-1}$ enabling thus saving 46% of energy as compared with CT. NT can reduce work duration too. Changing CT with NT enable us to save approximately 64% of work duration over the season.

Table 5. Total energy and total time requirement of two tillage methods to crop production of durum wheat.

Tillage	Fuel consumption $L.ha^{-1}$	Energy requirement $MJ.ha^{-1}$	Work duration h
2004/2005 season			
Conventional tillage (CT)	68	2631.6	9.75
No-tillage plot 1 (NT1)	35	1354.5	3.2
No-tillage plot 2 (NT2)	37	1431.9	3.4
2005/2006 season			
Conventional tillage (CT)	64	2476.8	9.35
No-tillage plot 1 (NT1)	37	1431.9	3.14
No-tillage plot 2 (NT2)	37	1431.9	3.14

Further comparison of tillage systems was done to better understand the energy requirement to obtain grain yield (Figure 1). To prepare the soil for sowing in CT, we need 233 and 261 MJ to produce 1 Mg of grain yield in the first and second season, respectively. While the maximum energy requirement in NT is just 100 MJ.

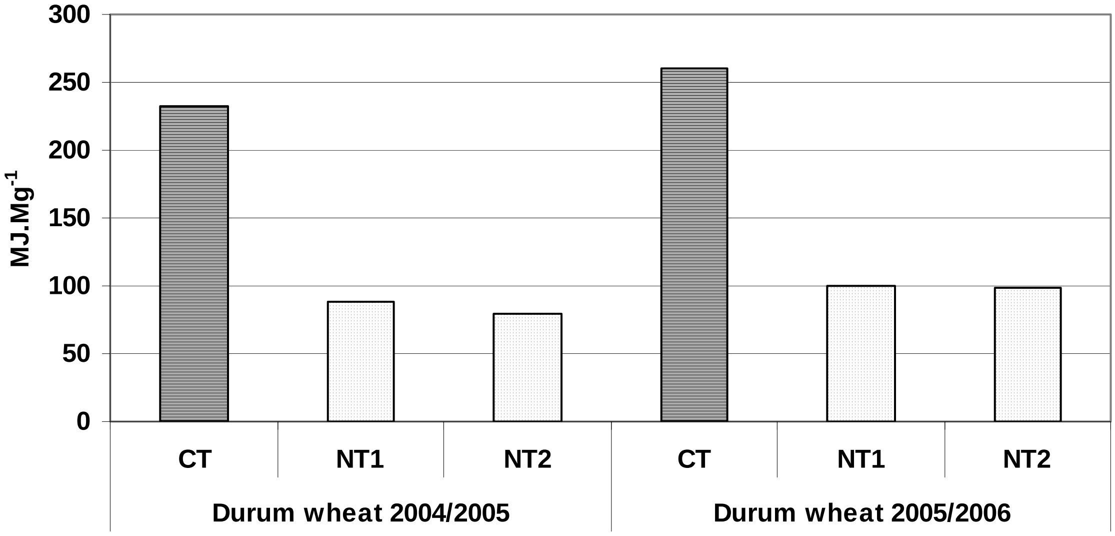

Figure 1. Energy requirement of two soil tillage methods to prepare the soil for sowing durum wheat with respect to energy requirement to obtain grain yield.

CONCLUSIONS

The effects of no-tillage (NT) and conventional tillage (CT) on durum wheat yield was investigated. Moreover, fuel consumption, energy required and work duration for soil preparation and crop production under these two tillage systems were calculated. The results of this study indicate that grain yield of durum wheat is higher in CT system. Lower yield under NT may have been associated with the development of cereal leaf beetle (Oulema melanopus L.) and lower emerged plant number compared with CT. While, NT provided a considerable saving in work duration, fuel consumption and energy required for either crop production or seed bed preparation.

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