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Assessment of the Use of Conservation Agriculture on Durum Wheat Yield, Water and Nitrogen Use Efficiencies and Soil Health

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Introduction

Durum wheat (DW) is a major crop in Tunisia as it is the base of the local diet. It occupies more than 50% of the area occupied by cereals and the mean production cover about 70% of national demand (Bachta, 2011). This deficit penalizes the country's trade balance since it is filled by importation of variable quantities of DW and bread wheat depending of the annual production. In fact DW production is highly variable and closely linked to variability of the precipitation amount during growing season (Latiri et al., 2010). On the other hand, soil degradation due to intensive land cultivation based on multiple tillages poses serious challenges to agricultural sustainability and on food security of the country. In fact, the tillage-based agriculture contributes to soil structure disruption, soil organic matter and associated soil life and biodiversity depletion (Gathala et al., 2011). In Tunisia, soil erosion is the main threat causing on-site and offsite damages in wheat growing-area. These disturbances will be accentuated in the future due to climate change, seriously striking all Tunisian regions (GIZ, 2007; Lhomme et al., 2009), which has been qualified as the « hot spot for climate change» (Giorgi and Lionello, 2008). This alarming situation requires a sustainable intensification of wheat based-system by improving the natural resources uses. In this perspective a group of crop management practices termed “conservation agriculture” (CA) are widely promoted to increase crop yields, reduce soil degradation and develop systems that are more resilient to climate change (Kassam et al., 2009; Mrabet, 2011). CA is based on three complementary pillars: i) reduced tillage, ii) retention of adequate levels of crop residues and permanent soil surface cover, iii) Crop diversification and use of adequate crop sequences.

CA is well known as a mean to restore soil degradation and to maintain soil security. CA allows to increase water infiltration and to reduce water evaporation and erosion (Thierfelder and Wall, 2009). By protecting the soil surface from direct impact of high-energy raindrops, soil surface cover in CA prevents surface-sealing and thus maintains the soil’s infiltration capacity, while at the same time minimizing soil evaporation (Jemai et al., 2012). Moreover, CA-practicing farmers stabilize their rainfed cereal production, even in slight-drought years, securing therefore a minimum income (Fredenburg, 2012). The economic benefits of CA include savings in expenditures on fuel, labor and time as well as water conserving.

In Tunisia, CA was introduced since 2000 and nowadays more than 200 farmers are practicing this system, over an area of 12000 ha mainly in durum wheat. Apart of limited availability of affordable no till seeder, this low adoption of CA is in part due to the CA strict proscriptive approaches followed by farmers. So, the use of a no till seeders, even considered as a key component of CA, specific agronomic practices (management and crop rotations) should be developed and fine-tuned to optimise the wheat production. For example we assume that the use of the no till seeder combined with legumes-based rotation would change the nitrogen dynamic in the soil-plant system under semi-arid condition of northern Tunisia. On the other hand the mistaken perception of farmers that soil tillage is essential for production inhibit the adoption of CA. Farmers and policy makers should be encouraged to adapt the CA-general concept to meet their specific situations leading to extension of CA surface across the cereal production area.

Nitrogen (N) is the nutrient most commonly limiting Durum wheat production for no-legume crops N can be provided by soil through soil organic matter mineralization et/or through mineral nitrogen fertilizer application.

In this context, this study aims to assess the effect of nitrogen fertilization of DW under tow tillage systems (CA vs CV) combined with two contrasted crop rotation (cereal monocropping, forage legume/cereal), on (i) crops yields, (ii) water and nitrogen efficiencies and (iii) soil quality.

Materials and Methods

Experimental site

To achieve the objectives of this study, we implemented in the framework of a long term trial set up by INRAT in the region of Bourabia (25 km south east of Tunis, 36°36'5.7"N, 10° 7'23.5"E, Figure 1) the effect of nitrogen rate under CA in comparison of conventional agriculture (**CV**: control) on crop yield and soil quality.

The experimental trial was organized based on a split-plot model with three factors. the plot size being 50 m^2. The main factor is tillage system (**Syst**: **CA** vs conventional agriculture with tillage) (Figure 2). Five mineral nitrogen rates (**Nrate**: N0=0, N1=75, N2=100, N3=120 and N4=140 kg $N.ha^{-1}$) were tested combined with two contrasted rotations (**PC**: monocropping of DW or DW rotated with vetch).

The DW cultivar used was 'Maali' which was registered on October 2003 and characterized by high production performance, drought-tolerant, resistant to lodging, medium-tolerant cultivars to main diseases and it supposed to be suitable for rain-fed farming in semi-arid regions of Tunisia (Deghais et al., 2007). The sowing rate was 150 $Kg.ha^{-1}$ (350 $grain.m^{-2}$).

Initial soil characterisation was done in triplicate on 0 to 40 cm soil depth using an auger for physical and chemical analysis. Bulk density was measured to a depth of 40-cm using the core-ring method. The textural class was determined by the United States Department of Agriculture (USDA) system. The soil is deep brown calcareous with clay-loam texture and organic carbon content of 0.73%. pH is equal to 7.1 and the average bulk density is 1.6 $Mg.m^{-3}$.

The climate of the Bourabia is upper semi-arid, with average annual rainfall of 400 mm.

Figure 1: Location of the experimental research station of INRAT-Bourabia.

Figure 2: Photo of experimental trial at INRAT-Bourabia station.

Measurements

Crop measurement

Observations were recorded on DW grain yield, which is estimated on 0.25 m^2 of each treatment with three replications. Nitrogen analysis in DW biomass and grain were performed using the Kjeldahl method (Bremner, 1965).

Water use efficiency in grain (WUEg in $kg.ha^{-1}.mm^{-1}$) is calculated here as the ratio between grain yield per hectare and the total amount of rainfall during the growing season. Nitrogen use efficiency (FPP in $kg.kg^{-1}$ N) is estimated by the ratio between grain yield per hectare and the amount of mineral nitrogen fertilizer added.

Soil measurement

After crop harvesting, soil was sampled and soil organic carbon content according Walkley-Black method (Walkley and Black, 1934) and soil aggregate stability according ISO/FDIS 10930 protocol (Le Bissonnais, 1996) were assessed.

Data analysis

These measured variables were analysed using the MIXED procedure (Littell, 2006) and preformed with Dunnett's method for comparing treatment group means. Regression analysis was done using Excel software.

Main Results

Crops Parameters

There is significant effect of previous crop (PC: monocropping vs rotation wheat-vetch) and nitrogen rate (Nrate) on DW grain, at 1% and 0.1% level, respectively. The tillage system effect is not significant ($p>0.05$) with a grain yield of 2543 $kg.ha^{-1}$ under CA and 2497 $kg.ha^{-1}$ under CV. However the two-way interaction of Syst * PC and Syst * Nrate are significant at 1% and 5% level, respectively (Table 1).

For the nitrogen use efficiency (FPP) the effect of previous crop and nitrogen rate are significant, both at 1% level of significantly. There is significant difference in WUEg by PC ($p<0.001$), by Nrate ($p<0.01$) and by the two-way interaction of (syst * PC; $p<0.01$) and (syst * Nrate; $p<0.05$) (Table 1).

Table 1: Mean comparison (Anova) between treatments and interaction study. Syst: Tillage system; PC: Previous crop; Nrate: Nitrogen rate. GY: grain yield, FPP: nitrogen use efficiency, WUEg: water use efficiency in DW grain.

Source of Variation	**GY**	**FPP**	**WUEg**
Syst	NS	NS	NS
PC	**	**	***
syst*PC	**	***	**
Nrate	***	***	**
syst*Nrate	*	NS	*
PC*Nrate	NS	NS	NS
syst*PC*Nrate	NS	NS	NS

Previous crop has significant effect on DW grain yield with an increase of 340 $Kg.ha^{-1}$ when vetch is the PC (2690 $kg.ha^{-1}$) in comparison with wheat as PC (2350 $kg.ha^{-1}$) (Figure 3). This is mainly due to the amount of residual nitrogen left into the soil by vetch, which a forage legume. The nitrogen use efficiency (FPP) and water use efficiency (WUEg) are larger with vetch as PC compared to wheat as PC (Figure 3).

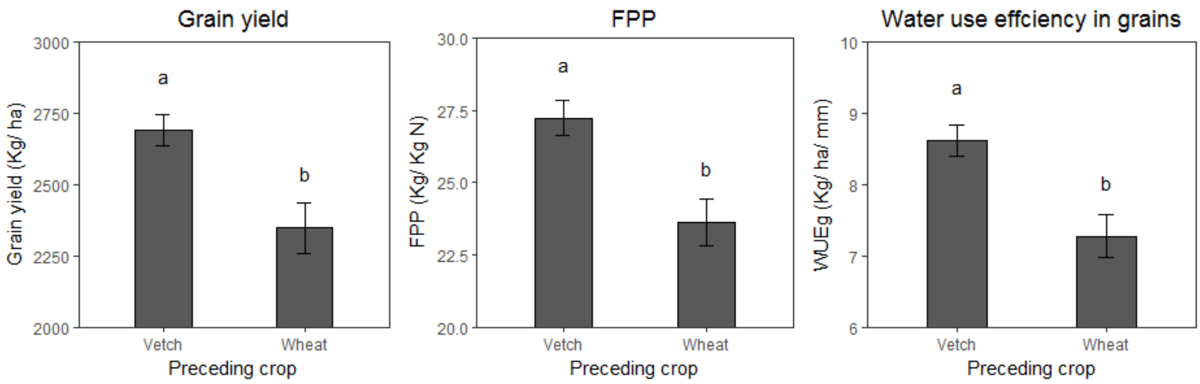

Figure 3: Effect of previous crops on DW grain yield, nitrogen use efficiency (FPP) and water use efficiency (WUEg).

For the three parameters (GY, FPP and WUEg) the two-way interaction (syst*PC) is statistically significant (P<0.01 to p<0.001) (Figure 4). CA treatment combined with vetch as PC gives the best level of DW grain yield, FPP and WUEg, which is respectively 2865 kg.ha^{-1}, 30.3 kg.kg^{-1} N and 9.4 kg.ha^{-1}.mm^{-1}. The other combinations between tillage system and previous crop are statistically similar for the three measured variables.

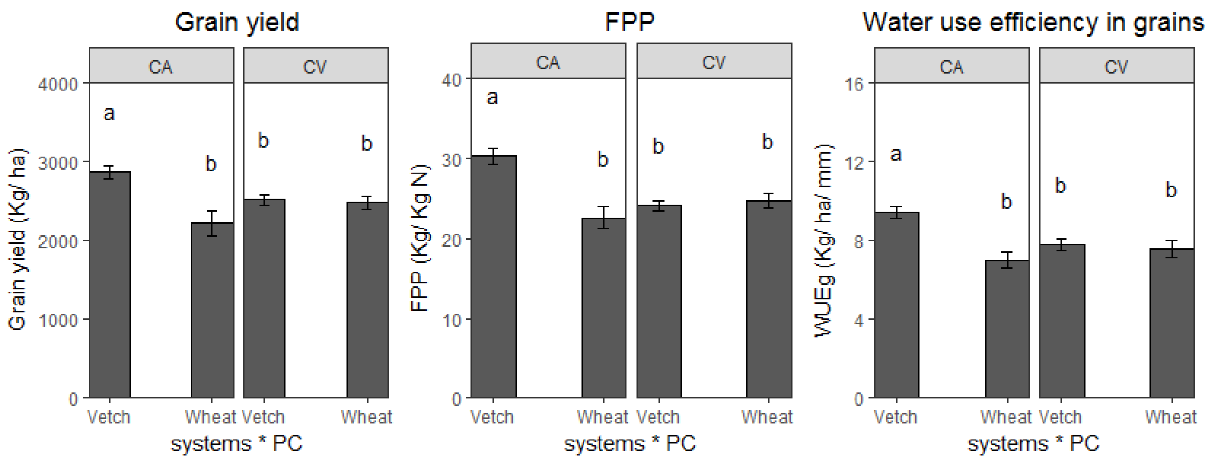

Figure 4: Interaction effect of tillage system and previous crops on DW grain yield, nitrogen use efficiency (FPP) and water use efficiency (WUEg).

When we compare the grain yield between the five nitrogen rates tested (Figure 5), we observe an increase of DW grain yield with nitrogen rate increase, from 2013 kg.ha^{-1} for control to 2920 kg.ha^{-1} for N4 (140 kg N.ha^{-1}). The best grain yield obtained is with N4= 140 kg N.ha^{-1}. On the other hand, the nitrogen efficiency (FPP) decreases significantly with nitrogen rate increase, from 34 kg.kg^{-1} N (N1= 75 kg N.ha^{-1}) to 21 kg.kg^{-1} N (N4= 140 kg N.ha^{-1}) (Figure 5).
Nitrogen rate has significant effect on WUEg with the best WUEg level (9.0 kg.ha^{-1}.mm^{-1}) being obtained at N4 (140 kg N.ha^{-1}) and the lowest WUEg (6.4 kg.ha^{-1}.mm^{-1}) at N0 treatment. However, there is no significant difference between the effect of N1, N3 and N4 on the WUEg.
The two-way interaction is significant between Nitrogen rate and tillage system for DW grain yield and WUEg at 0.05 level (Table 1).

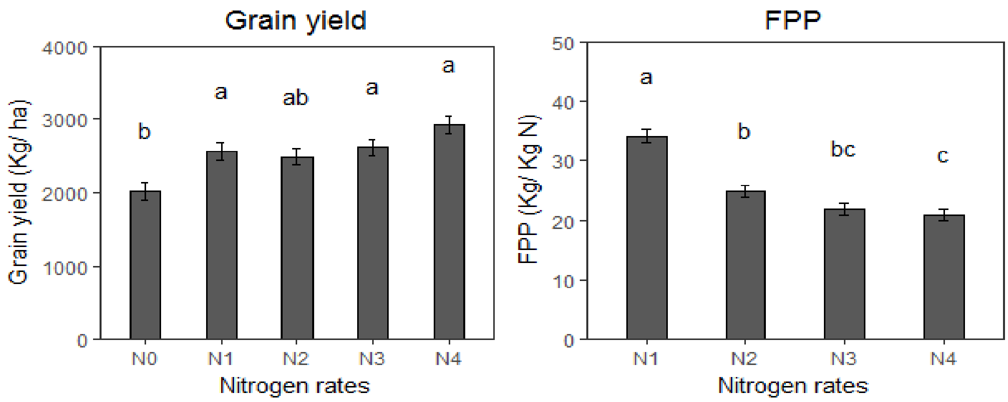

Figure 5: comparison of DW grain yield (left) and nitrogen use efficiency (FPP) between the different nitrogen rates tested.

The relationship between nitrogen use efficiency (FPP) and water use efficiency (WUEg) for all the tested treatments (tillage system * nitrogen rate * previous crop) is positive and statistically significantly (R^2= 0.32, p<0.05) (Figure 6).

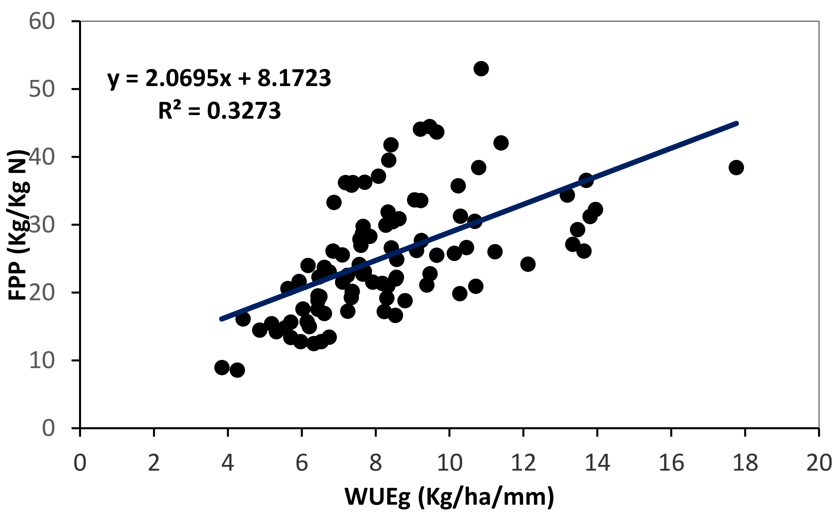

Figure 6: Relationship between nitrogen use efficiency (FPP) and water use efficiency (WUEg) recorded in all tested treatment (tillage system * nitrogen rate * previous crop).

Dilution curve building: a tool for monitoring N-fertilization

Critical N dilution curve is an interesting tool to manage N; It is defined as the minimum concentration of N required in shoots at a given time to maximize the aboveground biomass. Critical N dilution curve is built as the relation the amount of DW biomass (in dry matter) and its N-content.

The figure 7 compare the critical N dilution curve for durum wheat cultivated under CA vs CV according the different N-rate tested. The results show that the critical N-dilution curve for durum wheat for the both systems (CA and CV) were similar and described by the equations

N_c= 3.09 $DM^{-0.36}$ and N_c= 3.38 $DM^{-0.38}$ respectively for CA and CV when aboveground biomass was between 1 and 11 T DM ha^{-1}. When aboveground biomass was <1 t DM ha^{-1}, the constant critical value was N_c= 3.86 %DM for both systems, which was independent of aboveground biomass. The models accounted for 82% and 70% of the total variance, respectively for CV and CA.

This simple tool helps farmers to better manage N fertilization in order to ovoid N-excess and improve their outcomes.

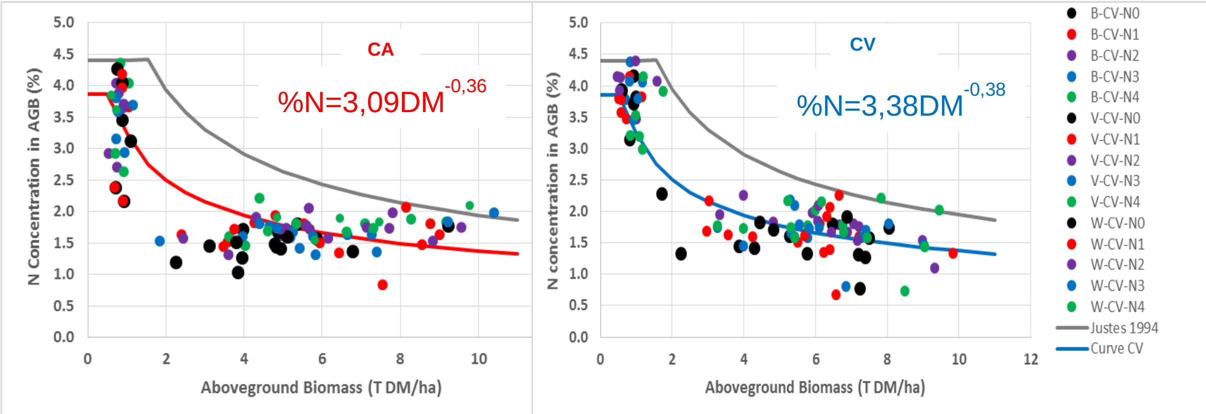

Figure 7: N-dilution curve for durum wheat under agriculture de conservation (CA) and conventional agriculture (CV).

Soil parameters

Soil organic carbon content

Soil organic carbon (SOC) is an important determinant of soil fertility, productivity and sustainability. This parameter is often used as a useful indicator of soil quality and tillage plays an important role in soil organic carbon dynamics.

An increase of SOC was observed after the implementation of CA (independently of N rate applied). The initial level represents soil under wheat in conventional tillage where the SOC content was about 0.73 %. However, it was about 0.92 % (mean of the two tested PC) after CA introduction (Figure 8). This increase is due to the retention of fresh crop residues, which is higher in CA compared to CV. The SOC content in crop rotations under CA (wheat/vetch) is higher than (wheat monocropping) (Figure 8). This result combines the effect of introduction of CA and crop rotation and confirms the importance of crop rotation in CA system.

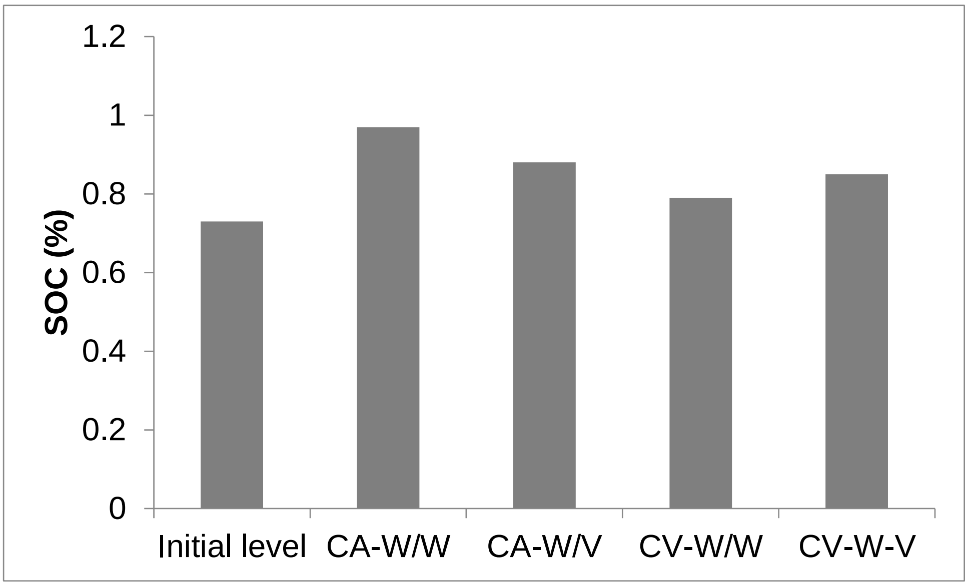

Figure 8: Soil organic carbon content (%) in the different treatments (independently of nitrogen rate applied): CA= conservation agriculture; CV= conventional agriculture; W/W= monocropping of wheat; W/V: wheat rotated with vetch.

Soil aggregate stability

Soil aggregate stability was evaluated by measuring the Mean Weight Diameter (MWD) index according to Le Bissonnais (1996) method. Soil aggregate stability is in interesting indicator of soil erosion sensitivity. Higher the MWD, better is the resistance to water erosion. At the outset, the MWD was about 0.57 mm (Figure 9).

The introduction of CA induced an increase of MWD from 0.69 mm to 0.70 mm for CA respectively for W/W or W/V the V/W sequence (Figure 9). For CV system, results show also an increase of MWD with a level of 0.63 mm for both rotation type (W/W or W/V).

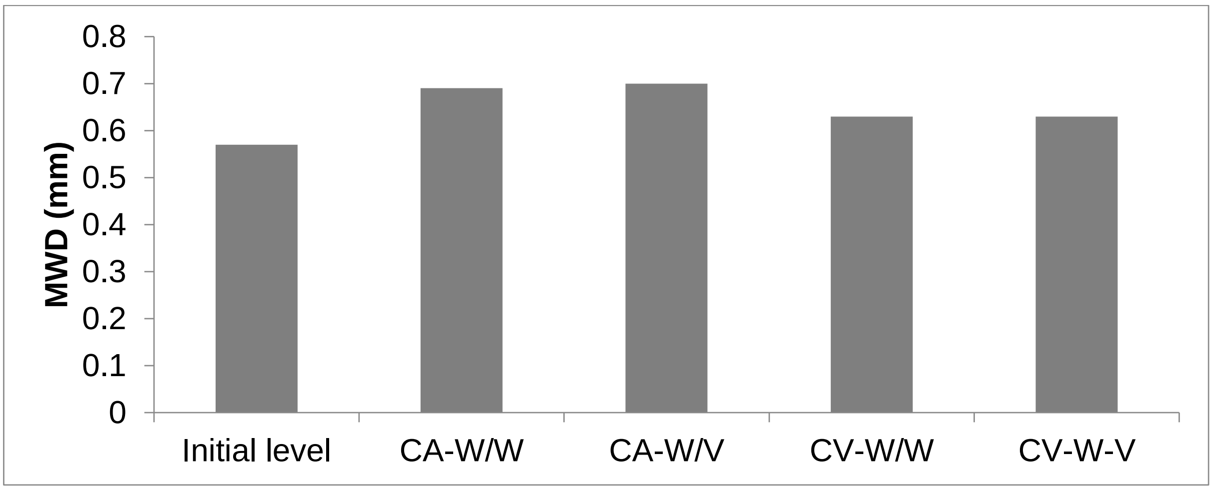

Figure 9: Soil aggregate stability (MWD in mm) in the different treatments (independently of nitrogen rate applied): CA= conservation agriculture; CV= conventional agriculture; W/W= monocropping of wheat; W/V: wheat rotated with vetch.

Despite this increase, all soils still present a high risk of erosion according to Le Bissonnais (1996) classification. The effect of crop rotation type on aggregate stability is not significant but does show a positive trend which may need a longer time for a clear demonstration. This must be considered as part of further work on the introduction of CA in agricultural regions in Tunisia where soils are affected by erosion.

References

Bachta M.S., (2011). La céréaliculture en Tunisie : Une politique de la régulation à repenser. Les notes d'analyse du CIHEAM 64. 19 p.

Bissonnais Y., (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. Eur. J. SoilSci. 47 : 425-437.

Bremner, J.M., (1965). Organic forms of nitrogen, p. 1238-1255, In ed. Black, C. A. Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, Vol. 9. ASA, Madison, Wisconsin, USA.

Fredenburg P., (2012). Conservation agriculture: opportunities for intensifying farming and environmental conservation in dry areas. ICARDA Ed.

Gathala M.K., Ladha J.K., Saharawat Y.S., Kumar V., Kumar V., Sharma P.K., (2011). Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice–wheat rotation. Soil Sci. Soc. Am. J. 75 : 1851–1862.

Giorgi F., Lionello P., (2008). Climate change projections for the Mediterranean region. Glob. Planet. Change 63: 90-104.

GIZ., (2007). Stratégie nationale d'adaptation de l'agriculture tunisienne et des écosystèmes aux changements climatiques Tunis: République Tunisienne Ministère de l'agriculture et des ressources hydrauliques.

Jemai I., Ben Aissa N., Ben Guirat S., Ben Hammouda M., Gallali T., (2012). On-farm assessment of tillage impact on the vertical distribution of soil organic carbon and structural soil properties in a semiarid region in Tunisia. Journal of Environmental Management 113: 488-494.

Kassam A., Friedrich T., Shaxson F., Pretty J., (2009). The spread of Conservation Agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability, 7 : 292–320.

Latiri K., Lhomme JP., Annabi M., Setter T., (2010). Wheat production in tunisia: Inter-annual variability and main determinants. European Journal of Agronomy 33 : 33-42.

Lhomme J., Mougou R., Mansour M., (2009). Potential Impact of Climate Change on Durum Wheat Cropping in Tunisia. Climatic Change, 96: 549-564.

Littell R.C, Milliken G.A., Stroup, W.W., Wolfinger R.D., (2006). SAS System for Mixed Models, Cary, NC: SAS Institute Inc.

Mrabet R., (2011). No-tillage agriculture in West Asia & North Africa. In. Rainfed farming systems. Tow, P.G., Cooper, I.M., Partridge, I, & Birch. C.J. (Eds). Springer, Dordrecht Netherlands, pp.1015-1042.

Thierfelder C., Wall, P.C., (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil & Tillage Research, 105 : 217–227.

Walkley A., Black A., (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci, 37 : 29-38.