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Effect of Tillage Practices and Cultivation Year on Natural Mycorrhization and Mineral Uptake of Durum Wheat during Tillering Stage under Rainfed Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. Authors NC, SL, SA, FBJ and MBH designed the study, performed the statistical analysis and wrote the protocol. Authors NC, SL and SA wrote the manuscript. Authors LM and AC installed the trials and applied necessary management practices. All authors read and approved the final manuscript.

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ABSTRACT

Conservation agriculture has been proposed as an alternative to conventional agriculture to mitigate the climate change impact and ensure food security. This study examined the effect of conventional tillage (CT) and no tillage (NT) on mycorrhization and mineral elements uptake of durum wheat for three cultivation years during the tillering stage. The experiment was conducted in a referential farm (Krib, Siliana, North West Tunisia). The results showed that tillage practices (T) had significant effect on mycorrhization rate (MR) for the first cultivation year and the highest mycorrhization rate was noted for NT with 24%. Moreover, tillage (T) had no significant effect on plant mineral composition in tillering stage for the three cultivation years. The cultivation year (Y) had showed significant effects on P and K amounts for both tillage practices when it had no effect on Ca and Na amounts. The interaction T x Y had no significant effect on mineral elements concentration. Mycorrhization rate (MR) showed significant negative correlation with K. For partial correlation based on Tillage practices, MR showed significant negative correlations with P and K. Considering the partial correlation based on cultivation year, MR had no significant correlations with the studied parameters (P, K, Ca and Na concentrations). This work expands our knowledge on durum wheat natural mycorrhization and mineral elements uptake as influenced by tillage practices helping decision makers in upscaling the adoption of no tillage in Tunisia under rainfed conditions

Keywords: Tillage practices; cultivation year; durum wheat; natural mycorrhization; mineral elements.

1. INTRODUCTION

Food global demand increase needs a satisfying and sustainable crop production. In the Mediterranean area, one of the main cultivated and consumed crops is durum wheat (*Triticum durum* Desf.). Durum wheat proteins, mineral elements and fiber makes it contributes to human diet as a main staple food [1]. However, during its growth, plant chemical and biochemical composition could vary according to environments factors. Lavado et al. [2] found that nutrient concentration could be affected by management practices such as tillage.

In Tunisia, durum wheat production satisfies only 30% of the country demand and 46% of the cereal area is concentrated on durum wheat and lead to 68% of cereal production [3]. Nevertheless, climates changes added to the problems of cultivars adaptation to agro-ecological zones and unbalanced socio-economic conditions threaten wheat production sustainability.

Around the world, cereal farmers are used to till their soils twice a year before sowing in conventional agriculture. However, aridity, soils vulnerability and inappropriate agricultural practices lead to erosion [4]. In conventional tillage (CT), tillage operations serve to control weed, to prepare seedbed and to prevent crust formation. Accordingly, CT associated to monoculture and overgrazing lead to soil moisture loss, soil physical properties destruction, and soil organic matter reduction [5].

In such situations, conservation agriculture has a potential as an alternative to conventional agriculture. In 1999, conservation agriculture based on NT was introduced in Tunisia under rainfed conditions [5]. According to Bahri et al. [6], there are about 260000 ha of agricultural area which must be priorities for conservation agriculture adoption in Tunisian semi-arid and sub-humid regions.

Since the worldwide adoption of conservation agriculture, many studies have reported its effect on soil physical properties, crop yield, soil moisture and organic matter [7]. Grain yield could be stable, increase or decrease under no tillage [8]. This effect depends on weather conditions, crop sequence, rainfall and on the interaction between many others parameters [9-10]. Moreover, no tillage is acknowledged to improve soil physico-chemical properties, soil organic matter, soil moisture and biological processes [5,7]. In contrast, few research activities have been concentrated on the tillage effects on mycorrhization and grain quality. This is despite the tillage effects noted on sucrose content [8], hormone activity [11], protein and gluten content [12]. In addition, a considerable increase of arbuscular mycorrhizal fungi (AMF) spores was observed for no tillage practices under semi-arid conditions [13]. In fact, cereal species cultivated under no-tillage stimulated interactions between the root system and the symbiotic fungi [14-16].

Mycorrhization, as roots-fungi association, was noted since 600 Ma. Arbuscular mycorrhizal fungi (AMF) have the capacity to colonize roots of about 72% of vascular plants [17] forming then arbuscules [18]. These highly branched fungal structures are responsible of nutrient exchanges between plant roots and fungi. Thus, fungus provides efficiently water and nutrients to the host plant while plant gives carbon matter [19]. This association could play a major role in agroecosystems sustainability [20-22].

The main objective of this study was to determine the effect of tillage practices and cultivation year on natural mycorrhization and some minerals elements uptake of durum wheat during tillering stage in North West Tunisia.

2. MATERIALS AND METHODS

2.1 Trials Description

This study was conducted at the referential farm for direct drilling (Krib, Siliana) situated in northwestern Tunisia (36°22'24"N; 9°10'26"E; elevation = 460m). Krib had a specific microclimate ranged between superior semi arid and sub-humid with an average of annual precipitation of about 450 mm. The annual means of temperatures and rainfall for three cultivation years of the experimental site are presented in Fig. 1. The soil was sandy clay and relatively poor in organic matter (2.1%) and slightly alkaline (pH=7.6). The trial was established since 1999-2000 growing season and the sampling was performed during the three cultivation years 2015-2016; 2016-2017 and 2017-2018. The biannual crop-rotation was faba bean (*Vicia faba* L. minor) and durum wheat (*Triticum durum* L.) cultivar 'Karim'. Two tillage practices: conventional tillage (CT) and no-tillage (NT) were tested. CT consisted of reversible moldboard ploughing to 30-40 cm depth followed by secondary tillage with offset 15-20 cm for seedbed preparation and NT plots were seeded by a direct driller. For NT, weeds were controlled with glyphosate at a rate of 3 $l.ha^{-1}$. The seeding rates were 160 $kg.ha^{-1}$ for durum wheat and 120 kg/ha for faba bean. Fertilizers were surface added, durum wheat received 100 $kg.ha^{-1}$ of Di-Ammonium Phosphate at sowing and 300 $kg.ha^{-1}$ of ammonium nitrate half at early tillering and half at stem elongation stages.

2.2 Sampling and Measurements

For a preliminary analysis of mycorrhizal colonization, durum wheat samples were collected during tillering stage for the three cultivation years 2015-2018. Roots were cleaned then conserved in ethanol 50% until trypan blue coloration. The areal parts of collected samples were dried, ground, sieved and stored until mineral elements analysis.

2.3 Trypan Blue Coloration

To estimate the root colonization by Arbuscular Mycorrhizal Fungi (AMF), during tillering, 3 plants/plot were sampled during the three cultivation years: from 2015 to 2018. Wheat roots were placed in a solution of KOH (5%) to be clarified at 90°C during 20 minutes. To facilitate colorant fixation, roots were then emerged in HCl (2%) solution during 5 min. After filtration, roots were stained with Trypan blue as described by Phillips and Hayman [23]. Mycorrhization rates were calculated using the method of Mc Gonigle et al. [24].

2.4 Mineral Elements Determination

For mineral elements analysis, 1 g of dry sample were ashed in a muffle oven at 600°C for 6h, and mineralized with HCl. Mineral elements measurements were made in quadruplicate. Potassium, calcium and sodium concentrations were estimated using the flame photometry. Spectrophotometery was used to determine phosphorus concentrations [25].

2.5 Statistical Analysis

The Statistical Package for the Social Sciences software (SPSS 20.0, SPSS Inc., Chicago, IL, USA) was used for all statistical analysis to identify treatment effects and interactions (Two-way MANOVAand PEARSON correlation). If significant effects were noted ($p < 0.05$), DUNCAN post hoc test was used to check differences between variables.

3. RESULTS AND DISCUSSION

3.1 Mycorrhization Rate

As mycorrhizal symbiosis is known to increase plant water and nutrients supply, this study tries to elucidate tillage effects on the root colonization by AMF. Results of mycorrhizal colonization are showed in Fig. 1. Both tillage practices (T) and cultivation years (Y) had showed significant effects on mycorrhization rate (MR). For the first cultivation year, high significant difference was observed between CT and NT and the highest mycorrhization rate was noted for NT with a value of 24%. Even if NT had no significant effect on MR for the second and the third cultivation years, higher rates were noted compared to CT.

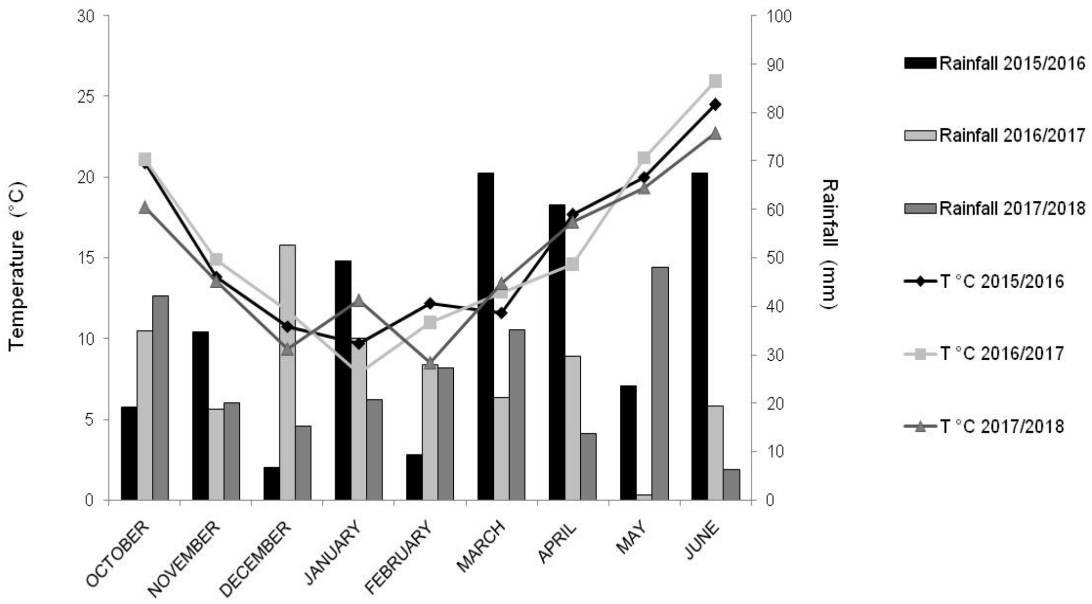

Fig. 1. Temperatures (°C) and rainfall (mm) recorded in the region of Krib from October to June during the cultivation years 2015-2018

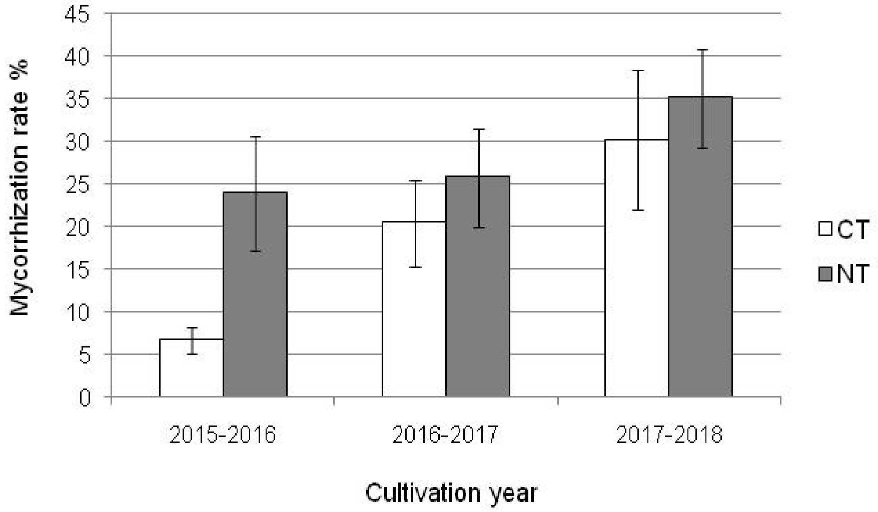

Fig. 2. Effect of conventional tillage (CT) and no tillage (NT) on mycorrhization rate of durum wheat (*Triticum durum* Desf.) during the tillering stage for the three cultivation years 2015-2018

These results are in agreement with those found by Kabir [26] who explained that soil disturbance has a negative effect on MR and thereby the benefic effect of AMF on soil quality. In similar, Roldan et al. [27] reported that no tillage showed the highest levels of bean and maize mycorrhizal propagules in the soil compared to tilled soils. Moreover, Curaqueo et al. [28] studied the effect of different tillage practices on mycorrhization rate of durum spring wheat in Chile. They reported that even if tillage practices had not significant effects on MR, higher values were noted with NT compared to CT. In Algeria, a study conducted by Hadj Youcef Taibi et al. [29] demonstrated an increase of durum wheat mycorrhization rate after three years of NT adoption compared to CT.

Table 1. Effect of tillage practices on phosphorus (P), potassium (K), calcium (Ca) and sodium (Na) concentrations of durum wheat in Krib during 2015-2018 cultivation years

	P (%)		K (%)		Ca (%)		Na (%)	
Tillage Practices	**CT***	**NT**	**CT**	**NT**	**CT**	**NT**	**CT**	**NT**
Cultivation year								
Year 1 2015/16	1.62 ± .29 a[1] A[2]	1.70 ± .45 a A	2.09 ± .02 a A	2.11 ± .11 a A	.14 ± .07 a A	.22 ± .12 a A	.34 ± .10 a A	.40 ± .10 a A
Year 2 2016/17	.04 ± .00 b A	.03 ± .00 b B	1.76 ± .1 b A	1.68 ± .23 b A	.04 ± .00 a A	.04 ± .01 a A	.59 ± .05 a A	.41 ± .32 a A
Year 3 2017/18	.06 ± .00 b A	.06 ± .00 b A	.18 ± .02 c A	.19 ± .02 c A	.08 ± .03 a A	.11 ± .07 a A	.43 ± .20 a A	.4 ± .12 a A

[1]In each column, values not followed by the same minuscule letters for the same treatment are significantly different (p=.05).
[2]In each line, values of the same mineral element not followed by the same majuscule letters for the same parameter are significantly different (p=.05)

There are various evidences in relation to the fact that tillage disturbs soils and decelerates their biological processes such as the decrease of mycorrhization rates under CT compared to NT [5]. Moreover, MR variability among cultivation year could be explained by climate effect on the establishment of this symbiosis [30].

3.2 Mineral Elements Concentrations

Minerals in plants act to maintain many essential physicochemical processes. With regards to macronutrients, phosphorus (P), calcium (Ca) and potassium (K) have particular functions in plants. They are components of nucleic acids, phospholipids, proteins, coenzymes, hormones, chlorophylls and adenosine triphosphate (ATP), etc.

The concentrations of phosphorus, potassium, calcium and sodium are presented in Table 1. Analysis of variance showed that tillage (T) had no significant effect on plant mineral composition in tillering stage for the three cultivation years. However, higher phosphorous concentration was noted under CT for the second cultivation year (2016/17). The cultivation year (Y) had showed significant effects on P and K for both tillage practices when it had no effect on Ca and Na. The interaction T x Y had no significant effect on mineral elements concentrations.

These results are in accordance with those of Ishaq et al. [31] who studied the tillage effect on nutrient uptake by wheat and demonstrated that P and K concentrations did not depend on tillage practice. Likewise, Singer et al. [32] found that tillage practices had not significant effect on P and K concentrations in corn cultivated in USA. In contrast, Chaieb et al. [33] found that tillage had a significant effect on mineral elements concentrations of durum wheat at maturity stage for a trial conducted under semi-arid conditions in Kef governorate (North West Tunisia). In addition, nutrients uptake as affected by dairy manure and tillage in corn was studied by Khan et al. [34] who found that NT presented lower significant concentrations of P and K in corn compared to CT. In China, maize cultivated under different tillage practices showed lower mineral elements concentrations for NT compared to CT [35].

Because of fertilizer management, crop residue and nutrients low movement into the soil, NT results in nutrients accumulation and concentration in the top few centimeters of soil and consequently, a decrease of the crop nutrients availability [36].

3.3 Correlation between Mycorrhization Rate and Mineral Contents

As shown in Table 2, mycorrhization rate (MR) showed significant negative correlation with plant K concentration. High significant positive correlations were found between P, K (r=.615) and Ca (r=.621) concentrations. For partial correlation based on Tillage practices (Table 3, a), other correlations were noted. MR showed significant negative correlations with P and K. P presented highly significant correlations with almost all measured minerals: K and Ca. Considering the partial correlation based on cultivation year (Table 3, b), MR had showed no significant correlations with the studied parameters. However, K presented highly significant negative correlations with P and Ca.

These results are in contrast with those showed by Garcia and Zimmermann [37] who concluded that plant K+ nutrition is clearly improved by mycorrhization. Moreover, Labidi et al. [38] found that mycorrhization increased mineral nutrient uptake of chicory. Likewise, Ingraffia et al. [39] compared nutrients uptake of wheat with and

Table 2. Correlation coefficients among mycorrhization rate and mineral elements concentrations of durum wheat under two different tillage practices in Kribfor three cultivation years 2015-2018

	MR[a]	P	K	Ca	Na
MR	1				
P	-.457	1			
K	-.564*	.615**	1		
Ca	-.188	.621**	.206	1	
Na	.228	-.213	.009	-.049	1

** Significant correlation p=.05.*
*** High significant correlation p=.01.*
[a]MR, mycorrhization rate; P, phosphorous, K, potassium; Ca, calcium; Na, sodium.

Table 3. Partial correlation based on tillage practices (part a) and cultivation year (part b) among mycorrhization rate and mineral elements concentrations of durum wheat

Table 3. (Part a)

Tillage Practices	MR[a]	P	K	Ca	Na
MR	1				
P	-.516*	1			
K	-.622**	.615**	1		
Ca	-.314	.631**	.213	1	
Na	.355	-.214	.007	-.011	1

** Significant correlation p=.05.*
*** High significant correlation p=.01.*
[a]MR, mycorrhization rate; P, phosphorous, K, potassium; Ca, calcium; Na, sodium

Table 3. (Part b)

Cultivation Year	MR[a]	P	K	Ca	Na
MR	1				
P	.095	1			
K	-.010	-.904**	1		
Ca	.100	.521	-.660**	1	
Na	.228	-.271	.239	-.017	1

** Significant correlation p=0.05.*
*** High significant correlation p=0.01.*
[a]MR, mycorrhization rate; P, phosphorous, K, potassium; Ca, calcium; Na, sodium

without mycorrhiza inoculation and they noted that mycorrhizae inoculation enhanced significantly K uptake when its effect on Ca and Na is not significant. Criado et al. [40] found that the efficiency of P utilization and remobilization was lower for inoculated plants compared to non inoculated plants of barley.

4. CONCLUSION

This work is a contribution to understand the relation between natural mycorrhization, mineral elements uptake as affected by tillage practices and cultivation year. The results showed that under rainfed conditions in North West Tunisia, tillage effect on natural mycorrhization of wheat depends on cultivation year. Moreover, tillage practices had no significant effect on mineral elements uptake. Then durum wheat quality is not affected by tillage practices. The results obtained in this work are encouraging for farmers who aim to adopt no tillage practices in North West Tunisia. These practices permit the soil conservation and enhance the sustainability of wheat cultivation in this region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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